

Improving Machine Utilization and Scheduling at Sjogren Industries

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Abstract

Sjogren Industries relied on manual scheduling to run overnight for two multitasking Computer Numerical Control (CNC) machines: the Okuma Multus and the Matsuura H-Plus 300. The goal of this project is to create a system that will automatically determine the optimal jobs to run overnight for each machine and display them in a way that is simple to understand. To accomplish this, our team utilized Microsoft Access and Microsoft Excel to create tools which sort customer order data, run optimization models, and display results in a manner consistent with Sjogren's current operations. Our team successfully implemented these tools into Sjogren's database, which generated schedules for running unattended jobs. Over a six-week pilot period, these tools achieved an approximate 44% increase in unattended hours compared to the previous year, and increased machine utilization over weekends as high as 100%. For future improvement projects, we recommend that Sjogren review its existing database system and data included within.

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Executive Summary

Introduction

This MQP focuses on process improvement at Sjogren Industries, a family-owned manufacturing company specializing in wire straighteners, straightener rolls, wire tooling equipment, and related products. To remain competitive in the market, Sjogren has asked our team to help increase unattended hours for two computer numerical control (CNC) machines in their Worcester location: the Okuma Multus and the Matsuura H-Plus 300.

Background

The Okuma Multus and Matsuura H-Plus 300

The Okuma Multus and the Matsuura H-Plus 300 are advanced precision machining centers capable of completing customer orders autonomously during unattended hours. At Sjogren, unattended hours refers to time when the machines operate without operators present, typically during nights and weekends. Several jobs (customer orders) can be run in sequence without an operator present.

Present Scheduling System

Sjogren uses Global Shop, an enterprise resource planning (ERP) tool, to manage jobs automatically. Global Shop jobs automatically arranges job information by machine in separate database tables, enabling a user to view jobs pertaining to a specific machine. Currently, job scheduling is done manually by Sjogren's foreman, who determines daily job schedules based on his experience and expertise.

Present Scheduling Limitations

Manual scheduling for overnight operations can be time-consuming and prone to error. If the foreman or other experienced Sjogren personnel are absent, inefficiencies or potentially dangerous situations may arise when a less experienced operator develops a schedule, leading to machine downtime.

Methodology

Directional Definition

To clarify our project's direction, our team broke up our broad goal of increasing unattended hours across the two CNC machines into two deliverables: one deliverable focused

on the Okuma, and the other focused on the Matsuura, each tailored to the machine's specific needs.

Understanding the Current Systems

During weekly interviews with the foreman on site, our team observed operations and machine processes, as well as meeting with machine operators to understand the operator's perspective on the production process. A significant finding from these interviews was the importance of Microsoft Access to Sjogren's daily operations, which influenced the design of our solutions.

Deliverable 1 – Maximizing Overnight Hours for the Okuma Multus

Choosing an Approach

Using our team's and Sjogren's existing Microsoft Access familiarity, we constructed SQL queries to optimize job selection using data provided by Global Shop and rule-based criteria. This approach played directly to the strengths of Microsoft Access as a data management software.

Creating a solution

Our team obtained sample job data for the Okuma from the foreman to construct a series of queries using existing conventions in Sjogren's Microsoft Access database. Through an iterative process that used ChatGPT, our team was able to consolidate these queries into a solution consisting of a single query. To improve user readability and ease of implementation, the single query solution was split into two queries, and integrated seamlessly into Sjogren's database for implementation.

Deliverable 2 – Maximizing Overnight Hours for the Matsuura H-Plus 300

Choosing an approach

To handle the Matsuura's sizing restrictions and multiple tombstone operations, our team decided that Microsoft Excel and its Solver Add-In connected to Microsoft Access was the best approach. This enabled an optimization approach to consider all possible job combinations across multiple available faces.

Creating a Solution

Our team obtained sample job data for the Matsuura from the foreman to construct (i) a series of queries using existing conventions in Sjogren’s Microsoft Access database and (ii) Microsoft Excel spreadsheets to calculate optimal jobs to run based on Sjogren’s physical restrictions regarding part heights. Connections between our Microsoft Access database and Microsoft Excel enabled automatic data flow, while Solver optimized the available data. Additionally, we used VBA macros to improve Solver functionality – the user clicks a single macro button to automatically run Solver on all sheets in the workbook and display the results in a single page summary.

Results and Analysis

Deliverable 1

Okuma Multus Work Backlog

Prior to implementing Deliverable 1, the Okuma accumulated a backlog of approximately 600 job-hours due to a mechanical breakdown. The breakdown lasted from November 8th, 2023, to January 5th, 2024, and should be considered when assessing our results.

Implementation

Our team collaborated with Sjogren’s foreman to implement Deliverable 1 by sending our code to a Sjogren computer which had access to Sjogren’s database. We were able to integrate the optimizing SQL queries successfully and quickly, and manually verified that the results returned from live Global Shop data were in fact optimal before leaving the site.

Results

Analysis of data comparing six weeks from January 8th to February 18th in 2023 and 2024 indicated positive impact. While keeping in mind the backlog on the Okuma, there was an approximate 44% increase in unattended hours in 2024 compared to 2023. Notably, weeks 1-3 saw unattended hour increases of 48%, 154%, and 156%, respectively, indicating a successful backlog clearance. Feedback from the foreman confirmed that machine utilization over the weekend peaked at 100%, using all 48 hours available on Saturday and Sunday.

Deliverable 2

Implementation

In the same manner as Deliverable 1, our team collaborated with Sjogren's foreman to implement Deliverable 2 by sending relevant files to a Sjogren computer which had access to Sjogren's database. Using our insights gained during testing, which indicated where attention needs to be given during Microsoft Excel and Microsoft Access connection implementation, we were able to integrate Deliverable 2 into Sjogren's systems in a streamlined manner.

Results

Due to time constraints, data for Deliverable 2 is presently being collected. However, post-implementation testing and manual verification of optimal results directly from live Global Shop data demonstrated the robustness and effectiveness of Deliverable 2. Despite the lack of data regarding unattended hours after implementation, similarities in functionality with Deliverable 1 and anticipated improvements over present scheduling methods for the Matsuura suggest that Deliverable 2 could result in relatively higher unattended hour increases for the Matsuura over the Okuma.

Continuous Monitoring

Both deliverables demonstrated promise in increasing future unattended hours for both CNC machines at Sjogren. While preliminary results from Deliverable 1 confirm a successful backlog clearance and optimized machine operation, Deliverable 2's similarities in design to Deliverable 1 and anticipated improvements over existing Matsuura scheduling methods promise further increases in machine utilization. Our team will remain in contact with Sjogren to determine the long-term efficacy of both Deliverables and potential ways to improve the solutions.

Conclusions and Recommendations

Introduction

Despite the successes achieved by Deliverables 1 and 2, it is critical to acknowledge limitations present in our solutions and recommend ways to improve the solutions.

Deliverable 1

Limitations

- While Microsoft Access is intended to handle large amounts of data, our team observed calculation times of up to 3 minutes on Sjogren’s hardware. This issue could worsen should Sjogren Industries expand in the future and need to handle larger amounts of data.

Recommendations

- **Hardware Improvement** – Sjogren should consider upgrading existing hardware to reduce calculation times, particularly if Sjogren Industries is considering growth opportunities or comparing a large number of jobs at once.

Deliverable 2

Limitations

- Microsoft Excel’s Solver can only handle up to 200 decision variables and 100 constraints in a single optimization problem, which may pose issues if the Matsuura experiences a mechanical breakdown and backlog generation similar to the Okuma.

Recommendations

- **Implement OpenSolver** – OpenSolver is a downloadable Microsoft Excel VBA Add-In that has the same capabilities as Microsoft Excel’s existing Solver, but allows for an infinite number of decision variables and constraints, granting unlimited scaling should Sjogren require.

General Recommendations

- **Adhere to Microsoft Data Formatting Conventions**
 - Ensure data types are consistent across columns (e.g., using numerical data types for Job Numbers), to prevent future implementation or calculation errors.
 - Review and update existing database data types to align with Microsoft’s suggested data type formats, enhancing future compatibility and improving ease of implementation.

1.0 Introduction

Major Qualifying Projects (MQP) are completed so that WPI students have an opportunity to apply the skills and knowledge learned in their major academic discipline to solve a problem representative of the type encountered in their career¹. Projects for Industrial Engineering majors tend to focus on increasing productivity, optimization of processes, and improvement in the efficiency of an existing working system.

This MQP focuses on process improvement at Sjogren Industries, a family-owned manufacturing company specializing in wire straighteners, straightener rolls, wire tooling equipment, and related products. Sjogren has continuously been improving its systems, processes, quality, and reliability since its founding by using the latest and most advanced technology available (Sjogren 2023), and presently competes with other wire straightener companies, such as Novo Precision, P/A Industries, and Component Supply (G. Collette, personal communication, October 5, 2023). To remain at the forefront of their competitors, Sjogren has asked our team to help increase unattended hours for two computer numerical control (CNC) machines in their Worcester location: the Okuma Multus and the Matsuura H-Plus 300.

The Okuma Multus and the Matsuura H-Plus 300 are highly advanced precision machining centers that have the capability of completing customer orders, which are referred to as jobs, without the presence of operators. Typically, the only times there would be no operator present at a machine is when Sjogren is closed, both at night and on weekends. The time it takes to complete jobs while Sjogren is closed is called unattended time, where the units of time are in hours—we call these unattended hours throughout the report.

Currently, job scheduling is done manually by Sjogren's foreman. Utilizing years of prior experience, the foreman can determine which jobs should be machined during the day, when employees can tend to the machines, or at night, when the machines are unattended. However, if the foreman or other experienced Sjogren personnel are absent, then Sjogren may not know which jobs to run, so a system is needed for others to be able to schedule and run jobs efficiently;

¹ <https://www.wpi.edu/project-based-learning/project-based-education/major-qualifying-project>

Sjogren heavily relies on the foreman's expertise regarding which jobs to run. While the foreman's expertise is extensive, it also introduces a degree of risk. Sjogren was interested in evaluating data-driven approaches to schedule jobs to address this risk.

In response, our team sought to create one automated system for each machine that will determine the optimal set of jobs to run overnight for that machine. An optimal set of jobs would maximize the number of hours required to complete all jobs scheduled to be run overnight. Each automated system would account for the following basic production criteria and constraints: due dates, program run times, materials needed, size of materials. We further detail machine-specific production criteria and constraints in sections 2.4 Okuma Multus and 2.5 Matsuura H-Plus 300. Such criteria and constraints determine which jobs can be safely run overnight without operators present. Furthermore, our team wanted these automated systems to easily integrate with Sjogren's existing systems and applications, and be simple enough to use so that any Sjogren employee may use it in the absence of highly experienced employees.

Our team utilized the following approach when creating the automated systems for each machine:

1. Gather information about the machine. Such information includes how schedules are produced for the machine, how raw material enters the machine, how the machine physically completes jobs, how operators interact with the machine, the terminology surrounding the machine, what software the machine utilizes, and the limitations the machine has, either physically or imposed as rules by Sjogren.
2. Determine the software to be used in the automated system. This determination is based on information gathered in Step 1.
3. Obtain sample data of jobs for the machine from the foreman.
4. Create a test environment for the automated system. This test environment is based on information gathered in Step 1, and utilizes the sample data obtained in Step 3.
5. Break down the problem into smaller parts. By breaking down the task of maximizing unattended hours into smaller parts pertaining to criteria and limitations learned in step 1, we would be able to see how each step in the process influences the next.
6. Develop and test the smaller parts. As the functionality for each smaller part is developed in the software determined in Step 2, it is tested in the test environment for all average

use cases and possible edge cases. If these parts behave as expected, they are approved. This step is to be repeated with each small part Step 5 creates.

7. Unite all smaller parts into one solution. With each individual part of the solution tested and approved, a single part is created to form the final solution.
8. Verify the final solution. Similar to testing in Step 6, the final solution is examined under average use cases and possible edge cases, and is approved only when it behaves as expected.

Upon completion of Step 8, our team would coordinate with the foreman to determine when we could visit the facility to implement our automated systems directly into Sjogren's systems.

The remainder of our report consists of background information required to understand why project decisions were made, a literature review regarding the practice and history of optimization and its implications for our project, our methodology for constructing solutions, the implementation process and analysis of data acquired after implementation, conclusions and recommendations to Sjogren regarding our project, and our team's reflection on this project.

2.0 Project Background

2.1 Introduction

This section provides the rationale behind the project's direction and why decisions were chosen. Subsections detail how scheduling fits into Sjogren's business and how Sjogren presently creates its daily manufacturing schedules.

2.2 Scheduling Workflow

Sjogren uses an enterprise resource planning (ERP) tool called Global Shop, which stores and manages customer orders (which we refer to as 'jobs') in a database without manual input. Through Sjogren's Access database, information from Global Shop jobs is automatically arranged by machine in separate tables in the database. This sorting is accomplished through router numbers; each machine has its own router number, linked to specific part types in jobs. Through this arrangement of jobs, we can view jobs only pertaining to a specific machine.

Within the machine tables in the Microsoft Access database, more details regarding job information are available, such as job due date, material type, and number of hours required for completion. We refer to these details as criteria.

At the start of each workday, both the Global Shop job list (Appendix A-1) and machine tables (Appendix A-2 and A-3) are printed on paper. From these two paper copies, a schedule of jobs for the day for each machine is created based on job criteria and "Daytime Priority", and is referenced by employees throughout the workday as jobs are run and completed.

We further define Daytime Priority as a set of rules that dictate which jobs should be run first during the day, when staff are available to perform changeovers. There are three rules that determine which jobs should be prioritized, which are detailed below in job from most to least important.

1. **One Piece Orders** are single jobs that take a short amount of time to machine.
2. **Due Date** is the date that the job must be fulfilled by; Due Dates that are closer to the present date take priority over Due Dates that are further away.
3. **Outside Services** are jobs that are made for companies to pick up on a set schedule from Sjogren, typically twice a week. As a pickup day approaches, certain jobs are moved up

in priority, dependent on which company is conducting the pickup and the previous 2 rules.

2.3 Present Scheduling System

Currently, the foreman manually creates a daily work schedule and breaks down jobs into three categories prioritized from highest to lowest: Sold Jobs, General Inventory, and Dynamic Inventory; these priorities are determined by the foreman. We next describe the three categories.

Sold Jobs consists of all customer jobs stored in Global Shop. This is the highest priority category because Sjogren's customers are waiting for these jobs, and most jobs fall into the Sold Jobs category.

General Inventory consists of products needed to maintain minimum stocking level and reorder points. A few of these products may be used to fulfil sold jobs. These jobs take second priority because they are considered as parts currently needed or will need to backfill Sjogren's reorder points and stocking limits.

Dynamic Inventory Products are similar to general inventory products but are based on quantity estimates from historical data and are produced up to calculated inventory reorder points, minimum stocking levels, and fill available machine time. These jobs are lowest priority because they attempt to utilize downtime on the machines and backfill free time, so the machines are always running.

Considering these priorities, along with the job completion time, the foreman manually creates a schedule of jobs to be run both during the day and overnight.

Certain jobs require employees to attend to the machines. Examples of such requirements include manually changing over drill bits, entering parameters into the machine's on-board computer, or observing new machine programs being run. Overnight jobs do not require employees to attend to the machines, so the hours the machines run are considered unattended hours. In contrast, the hours when employees *are* available are considered attended hours.

The manual scheduling can become time consuming when deciding what jobs to run overnight; machines typically require an employee to manually input size specifications per part type into the machine's local computer. Any lapse in human judgement while creating the

schedule can result in: running a sub-optimal number of job-hours, which must then be made up during attended hours; selecting a bar diameter that is not safe for the machine to use, potentially damaging the machine; or not scheduling the overnight jobs to start at the right time of day, creating excessive changeover times during attended hours.

Additionally, very few experienced employees outside of the foreman and owner have the knowledge to create schedules, so their absence(s) typically result in drastically inefficient daytime and nighttime operations.

For daytime operations with absent leadership, employees have a general, non-optimized list of jobs that they are able to work through without guidance, but only experienced employees would be aware of what needs to be run first. This results in “thrown-off” delivery dates because employees would be working on jobs in a suboptimal sequence.

For nighttime operations with absent leadership, the machine will not run *at all*, because no operators are programming it to run at the end of the day shift. This results in a substantial loss of potential overnight hours.

2.4 Okuma Multus

2.4.1 Machine Details

The Okuma Multus is a multitasking CNC machine, with an automatic tool changer and sub-spindle attachments.

Before parts can be machined, raw material must be fed into the machines’ magazine (Figure 2.1); this raw material is cylindrical in shape, and we refer to it as a bar. This magazine functions as a basket, which can store multiple bars, and has the capability to determine the remaining amount of material present in the magazine. However, the magazine is unable to distinguish between different material types of each bar. To resolve this issue, an operator uses the Okuma’s onboard computer to indicate when a change in material type occurs.



Figure 2.1 – The empty magazine of the Okuma Multus, viewed from the front.

When the Okuma begins machining a job, the magazine pulls a bar down into a bar loader, which then pushes the selected bar forward during the machining process. The distance that a bar is pushed forward during a job is determined by that job's stock length out, or SLO. As the machine works on multiple jobs, a bar is gradually shaved down until it is too small to safely machine, at which point the machine ejects the bar remnant into an external scrap bin.

2.4.2 Workflow

Bars for the Okuma are purchased directly from Sjogren's vendors, and do not need to be machined in-house. When these bars are delivered, they are stored on a rack directly behind the Okuma's magazine (Figure 2.2).



Figure 2.2 – Bar storage rack located behind the Okuma’s magazine, filled with bars.

For attended hours, operators run jobs scheduled by the foreman at the start of the day. In the absence of management during attended hours, operators are able to consult past schedules and current jobs to continue operations as normal; the simplicity of the bar loading mechanism minimizes operator errors, indicating that scheduling errors are the largest contributor to inefficiencies in Okuma job completion.

For unattended hours, Sjogren has placed restrictions on which jobs can be run on the machine to minimize the risk of machine malfunctions or damage. The first restriction is that only one material type can be used overnight, since the magazine cannot distinguish between two material types, and there is no operator present to indicate a change in material to the onboard computer. The second restriction is that the SLO of jobs queued to run must be in order from longest to shortest lengths in inches; the Okuma is incapable of automatically switching from low SLO values to high SLO values, but can automatically switch from high SLO values to low SLO values. When management is absent, operators typically load the machine with the first job listed on a schedule, loading that job’s material type. Then, jobs that only use that material are loaded first to last, stopping when the next available job has a higher SLO value than the previous job. This method of loading typically results in failure to maximize the potential overnight hours available on the Okuma.

2.5 Matsuura H-Plus 300

2.5.1 Machine Details

The Matsuura H-Plus 300 is a high-precision horizontal machining center, which operates on multiple axis to allow for the production of intricate and complex parts.

Integral to the function of the Matsuura is its use of tombstones. Here, a tombstone is a dynamic work-holding fixture; its name is derived from its similarities to actual tombstones, shown in Figure 2.3. Multiple tombstones are utilized by the machine to load and unload jobs, providing a constant workflow and minimizing downtime. Jobs are held in place on tombstones by faces, which act as vices.



Figure 2.3 – Tombstone #3 in Sjogren’s Matsuura H-Plus 300, viewed from Face A.

These faces vary by width according to the manufacturer’s needs. Each face is equipped with stops at every inch to provide precise spacing for machining multiple cut materials simultaneously. Figure 2.4 shows cut material being placed into a tombstone face using stops. The maximum height for every face is 23 inches, creating a large work area and allowing for safe

movement of the tombstone through the machine. Appendix B-1 shows the stops numbered on the side of the tombstone face.



Figure 2.4 – Cut material being placed into the third stop on Face C of Tombstone #3.

Sjogren has additional restrictions regarding faces that enhance safety and precision. There must be a minimum of 2 inches of clearance between each cut material on a face to prevent interference during machining. Moreover, parts can only be placed on the designated inch stoppers, contributing to the accuracy and repeatability of machining processes.

2.5.2 Workflow

Raw materials for the Matsuura jobs are cut by saws (separately from the machine) and placed into a cart as shown in Figure 2.5. This cart full of cut material is wheeled to the Matsuura, where the operator will select cut material(s) to place into the machine, based on which job they are going to run.



Figure 2.5 – Two carts containing cut materials, which are rectangular and silver in appearance.

Presently, the operator receives instructions from the foreman regarding which jobs to run during attended or unattended hours. In the absence of management, the operator will typically load the material by height, from largest to smallest, into each tombstone face. This method of loading does not consider the hours required for completion or complexity of the job being machined, and as a result is frequently sub-optimal for maximizing overnight production hours.

After the parts have been placed on the tombstone faces, as in Figure 2.4, the operator will use the machine's local computer to specify which stop, face, and tombstone each cut material is on, calibrating the machine to work on the correct material in the correct location. Upon running the machine, the tombstone will retract into the machine, and the operator may call another tombstone to repeat the process on the next job.

2.5.3 Cut Material Nomenclature

Sjogren's Microsoft Access database condenses two attributes of cut material for the Matsuura into a new attribute called "Operations", which is an abbreviated name indicating the material type and cut width. Abbreviations consist of 2 letters indicating material type, and 3 digits indicating cut length, where the first digit represents a whole number, and the two final digits represent decimal values. This project focuses on 5 Operations: HR125, HR200, HR300,

HR400, HR600, where HR stands for Hot Rolled and the digits correspond to widths of 1.25 inches, 2 inches, 3 inches, 4 inches, and 6 inches, respectively. It is important to note that Operations are a part of a job, just as the due date and job number, and do not indicate the height of the cut material.

Operations have fixed widths, meaning their jobs are typically machined on the same tombstone and face, with exceptions being due to two or more tombstones having the same width. An example of such an exception would be that tombstones 1, 3, and 4 each have one face that is capable of machining operation HR200, because these faces are 2 inches wide.

3.0 Literature Review

3.1 Introduction

This section begins by describing the practice of optimization and its history, providing a background for the type of work conducted in this project. It then discusses the application of optimization practices over time, and its implications for our project. Finally, the conclusion relates this information to the problem at hand, placing it into the context of Sjogren Industries.

3.2 History of Optimization

Optimization is colloquially defined as “doing the most with the least” (Gomez, et al., 2006, as cited in Kelley, 2010). The goal of optimization is to select the "best", or optimal, alternative relative to constraints or priorities. Examples of optimization models could include selection of an alternative which maximizes output, fortitude, dependability, endurance, effectiveness, and usage (Kelley, 2010). Engineers frequently work on design projects that call for them to find an effective way to formulate a design within the specified limits that satisfies the specified requirements. During the design process, they identify multiple solution alternatives to a problem and mathematically select a solution which best meets a decision objective of the decision-maker. This process is known as optimization.

The concept of optimization dates to the 1920's, when a famous aviator pushed the limits on airplane travel. Charles Lindbergh is the first aviator to fly nonstop across the Atlantic Ocean from New York City to Paris, France. More experienced aviators tried before him but either crashed on takeoff or were lost at sea (Kelley, 2010). Lindbergh succeeded not because of a more technologically advanced airplane, but because he optimized for the best available solution under the given constraints and conditions. He valued safety above everything, so the plane was flown with minimal weight, more safety equipment, and reserve fuel that was all equally considered or optimized to best aid his adventure. These factors were all given equal consideration.

Although some processes and decisions can be optimized by mental calculations, more complex problems require a more complex approach of applied mathematics called optimization. Optimization has foundations in linear algebra, vector calculus and ordinary differential equations. It was not until the 1940's that humans demonstrated this use of mathematics to optimize problems and demonstrated its applicability. Shortly after the end of World War II,

University of California Berkeley PhD graduate George Bernard Dantzig returned to work for the United States Air Force as a civilian. Dantzig “was challenged to automate the planning or *programming* process of developing detailed production requirements for producing, assembling, training, and locating all of the military's personnel and equipment” (Birge, 2022). To solve this problem, Dantzig had to optimize military operations and processes to save time, money, and other valuable resources. The model he created, assuming linear functions to relate activities and resources, became known as linear programming (Birge, 2022). Linear programming or linear optimization is a subset of optimization which utilizes mathematics and Dantzig used this along with an algorithm he constructed known as the “simplex algorithm” or “simplex method.” This algorithm allowed him to optimize a process with many variables and constraints to find the best feasible solution. This report will focus on the linear programming side of optimization and will go in depth about the application, design, and benefits of such.

Advancements in technology since the 20th century have profoundly transformed the landscape of linear optimization, ushering in unprecedented efficiency and precision. Linear optimization, a mathematical technique used to find the best outcome in a model with linear relationships, has seen substantial improvements by integrating sophisticated algorithms and powerful computational tools. Modern computing technologies, including high-performance processors and parallel computing architectures, enable the rapid and precise solution of complex linear optimization problems (Csalódi et al., 2021). Additionally, advancements in optimization software, leveraging machine learning and artificial intelligence, have led to more intelligent algorithms that can adapt and optimize solutions in real time. The availability of big data and advanced analytics tools further enhances the accuracy of input parameters, providing a more nuanced understanding of the variables in optimization models (Csalódi et al., 2021). Overall, these technical advances have accelerated the solution times of linear optimization problems and expanded the scope and applicability of this mathematical approach across diverse industries, ranging from logistics and finance to manufacturing and supply chain management.

3.3 Application of Optimization

In the global economy, the application of linear programming (a branch of optimization) has significantly increased productivity. An example of this can be seen in “industries with expensive capacity or limited production flexibility, such as airlines, hotels, rental cars, and

many retailers, revenue management models, built often on linear programming, have provided revenue increases of 5% or more” (Phillips, 2005, as cited in Birge, 2022). When looking at all industries in the United States such as manufacturing, telecommunications, healthcare, etc. and the benefits linear programming provided for them (Dilda et al., 2018, as cited in Birge, 2022), “the overall value of linear optimization to the economy probably surpasses 5% overall or more than \$1 trillion each year in the United States alone” (Birge, 2022). Linear programming models have not only benefited economies but also human health. This can be seen in recent examples such as determining the origins of organisms, such as viruses, electrical stimulation therapy, chemotherapy network design, discovery of drug targets, designs for radiation therapy, and finding optimal diets (Birge, 2022).

Relevant to our project, optimization has shown promise in the manufacturing sector in reducing machine downtime. A case study was done on one of the top plastic manufacturing companies in Nigeria that was experiencing a reduction in production efficiency. The goal of this study was to improve production efficiency by reducing downtime on machines. Downtime refers to a non-operable condition, when the machine is not ready for an assigned work (Nwanya, 2017). Downtime has an adverse effect on production rate and business profit so by minimizing this, it is positively impacting production time which positively affects profit. The company did this by formulating a linear program to optimize the scheduling of jobs that need to be done while adhering to all constraints and limitations the company has. After the results of the optimization model were implemented, “uptime was maximized by 332 min per shift operation thereby reducing the downtime” (Nwanya, 2017).

Another example of manufacturing can be seen in a private sector textile and fashion company (Georgiadis et al., 2022). A production scheduling linear optimization model was applied and demonstrated in the weaving process, which is a part of fabric production. Weaving poses a critical step in production, as optimizing scheduling of the orders to be processed determines the overall performance of the production pipeline. Each order is scheduled successively on a specific weaving machine (loom) and must be completed for the next to be processed. As a result, a single order delay may have an impact on the overall production's delivery schedule. Furthermore, the setup periods required for an order to be executed by a loom add to the complexity of the best order scheduling. The setup times might vary from a few minutes to several hours, depending on the characteristics of the cloth that the machine has

already treated. Unexpected incidents like shattered yarns, loom malfunctions, and order delays compound the complexity of the scheduling process. The main constraints of the production scheduling optimization problem are: (1) orders must finish before their deadline times, (2) production must be cost efficient, (3) high priority orders must be processed before low priority ones (Georgiadis et al., 2022). After the implementation of the linear optimization algorithm, the platform was pilot tested by companies in the industry. The proposed platform enables a rapid planning update, every time new orders are added to the production line or machine failures occur. The manufacturer estimates a “25% improvement in machines usages due to optimized scheduling that will reduce the idle time of machines” (Georgiadis et al., 2022). Furthermore, “the time for machines setup is expected to be reduced by about 15% and the overall productivity in the factory is expected to be improved by about 30%” (Georgiadis et al., 2022).

Another example can be found in the logo and label design industry. The woven label manufacturing company in this case study has 5 workstations: Ultrasonic splitting, coating, sizing, joining, and the cut and fold station. The company's present scheduling strategy was such that it is not possible to complete several orders in a single day. This means that there is no way to prevent late deliveries. Additionally, it makes shift transition periods more challenging. Current job completion is lengthy - 25 jobs take 53.5 hours to complete which is much longer than the 24-hour day (Wang et al., 2021). As a result, these jobs cannot make the delivery schedule for the customers. The new system was developed which introduced a preprocessing step before scheduling. In this step, jobs with big order amounts are divided into smaller jobs, and similar jobs with smaller order quantities are grouped together. With whole parameters, the model is constructed and solved using a linear optimization algorithm and executed in the CPLEX solver. In just nine seconds, CPLEX solves the problem, and the 25 jobs only take 20 hours for completion (Wang et al., 2021). This outcome demonstrates a notable enhancement of the overall performance where every task can now be completed in a single day.

3.4 Conclusion

This section discussed the history and applications of optimization, focusing on linear programming. It described how optimization aims to find the best solution given constraints and how linear programming utilizes tools like linear algebra and differential equations to solve complex problems. A critical early example was George Dantzig's development of the simplex

algorithm and linear programming in the 1940s to optimize military operations. The section then provides several case studies demonstrating how linear programming has been applied to improve efficiency in manufacturing by reducing downtime, optimizing production scheduling, and enabling companies to complete jobs and meet delivery deadlines in less time.

Optimization and linear programs may help Sjogren Industries productivity on the manufacturing floor, saving time, money and keeping customer satisfaction.

4.0 Methodology

4.1 Introduction

The overarching goal for our project was process improvement at Sjogren. After interviewing Sjogren's foreman to determine which issues were most pressing to the factory, we learned that maximizing the overnight production hours for two machines, the Okuma Multus and the Matsuura H-Plus 300, is a high priority and planned our project accordingly.

We broke up our goal into two deliverables: one deliverable focused on the Okuma, and the other focused on the Matsuura. Both deliverables shared the same end-goal of maximizing overnight hours, but had to be achieved through different approaches due to implementation limitations with how each machine's data interfaces with Microsoft Access and differences in each machine's material handling capabilities. The following sections detail our comprehension of current operations and our approach to each deliverable.

4.2 Understanding the Current System

To better understand the nuances within machine operations, our team congregated for weekly interviews with the foreman on site. These interviews provided insight into how each machine works, what limitations and strengths each machine has, the varying complexity of jobs, the scheduling process, flow of resources both into and out of the factory, as well as technological limitations that are being experienced. These weekly interviews included site tours, during which we observed operations and machine processes as well as meeting with machine operators to understand the operator's perspective.

A significant finding from these interviews was the importance of Microsoft Access to Sjogren's daily operations. All of Sjogren's customer jobs from Global Shop go directly to Access, operators look at reports created in Access to determine which jobs to run for their machine, and the foreman uses Access reports to schedule daily jobs to run for each machine. These three examples are small samples of Sjogren's Microsoft Access use, and our team recognized that any solution proposed had to incorporate Microsoft Access.

4.3 Deliverable 1 – Maximizing Overnight Hours for the Okuma Multus

4.3.1 Choosing an Approach

Given both our team’s and Sjogren’s familiarity with Microsoft Access, we assessed it was possible to develop SQL queries in Microsoft Access that would return an optimal list of all jobs to run for the night using Global Shop data and mathematics. We believe this approach is appropriate because any solution we create would, functionally, filter out all but the optimal jobs based on job hours, making Deliverable 1 a data management problem—a task Microsoft Access is designed to handle.

4.3.2 Creating a Solution

4.3.2.1 Initial Solution

To begin creating a solution, our team reached out to the foreman to obtain a sample of job data for the Okuma Multus. This would allow us to work with the exact criteria Sjogren uses to eliminate any potential misunderstandings.

After reviewing sample data, which contained jobs scheduled to be completed from October to December, we realized we would need to create a series of queries to produce our solution, due to the complexity of prioritization rules. We then created a visual schema (Figure 4.1) of our queries to map how information would be processed and what filtering was required. The visual schema enabled us to clearly see our objective being fulfilled and the steps necessary to achieve it.

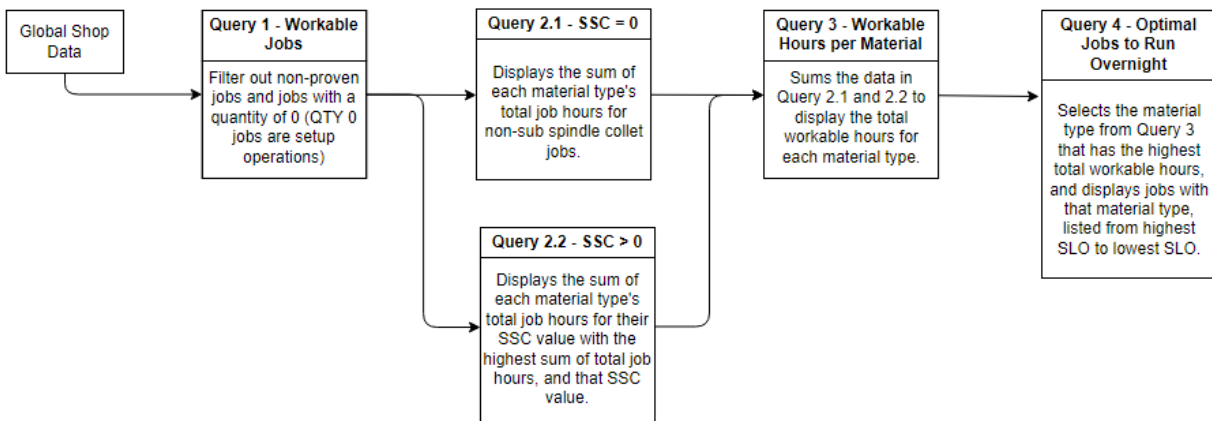


Figure 4.1 – A logical flow diagram detailing the functions, inputs, and outputs of the five queries used to complete Deliverable

1.

Queries were created one at a time in accordance with our schema and constituted a series of queries needing to be run with each query dependent on the output of the previous one. The final product was a series of queries that returned the maximum number of job-hours possible, adhering to all specified constraints. Appendix C provides the queries developed.

4.3.2.2 Polished Solution

Our team wanted to consolidate our queries for ease of use, since some queries are dependent on calculations produced in a sequence of previous queries. This consolidated query would not only be simpler to implement, but simpler to understand for any employee at Sjogren who should happen to use it.

With limited knowledge about higher-level subqueries in Microsoft Access, our team turned to ChatGPT, a generative natural-language-processing AI, to help consolidate our queries. We fed ChatGPT one pair of queries at a time, ran the code it provided, verified its output through manual calculations, and integrated it into our sample database. In the event we were unable to run code from ChatGPT, we would change our ChatGPT prompts or add further restrictions to our prompts until we received a desired output. In repeating this process several times, we were able to successfully return a single query that accomplished the same task as our previous series of queries.

Prior to implementation, we split our single query into two queries to increase user readability and make implementation easier. By using two queries, we only needed to connect the first query (Appendix D-2) directly to the Sjogren database, and the second query (Appendix D-3) did not need to be altered at all to function. The first query filters out all jobs that cannot be worked on overnight, such as job setups with no outputs or unproven programs to run a job, and displays a list of all workable jobs. The second query pulls from the list of workable jobs, calculates the optimal jobs to be run given Sjogren's constraints, and returns an optimal list of jobs to run that night.

Implementation-wise, Sjogren will only need to run the second query, due to our first query being an intermediary between Sjogren's database and our optimization query.

4.4 Deliverable 2 – Maximizing Overnight Hours for the Matsuura H-Plus 300

4.4.1 Choosing an approach

Our team’s approach revolves around the 5 Operations available to the Matsuura, with some Operations having the ability to be machined on multiple tombstones. With this fact in mind, queries in Microsoft Access alone would not be sufficient to create a solution for the Matsuura due to its sizing limitations on loaded cut material heights on each tombstone face. Our team decided to use Microsoft Excel with Solver, an Add-In optimization tool available in Microsoft Excel used to solve optimization problems. Because Solver is built into Microsoft Excel and can interface with Microsoft Access, integration of this tool into Sjogren’s existing operations would be relatively straightforward. Solver would allow our team to test multiple combinations of available jobs for each operation on multiple faces, if needed, and determine which combination has the maximum number of job hours.

Solver must be run within Microsoft Excel, requiring any Sjogren employee to launch our Microsoft Excel file. To simplify the optimization process, our solution was intended to be displayed on the first page of the Microsoft Excel workbook, with calculations and imported data present in separate spreadsheets within the workbook. The entire workbook would be protected using Microsoft Excel’s protect function to prevent accidental editing of cells during usage.

4.4.2 Creating a Solution

4.4.2.1 Microsoft Access

A series of queries was created using Microsoft Access that functioned similarly to those developed for Deliverable 1. One query would filter out jobs based on criteria in our visual schema (Figure 4.2) created for Deliverable 2, while five of these queries would display the available jobs for each type of Operation. By developing a unique query for each Operation, we would be able to import the parsed data more easily to Microsoft Excel.

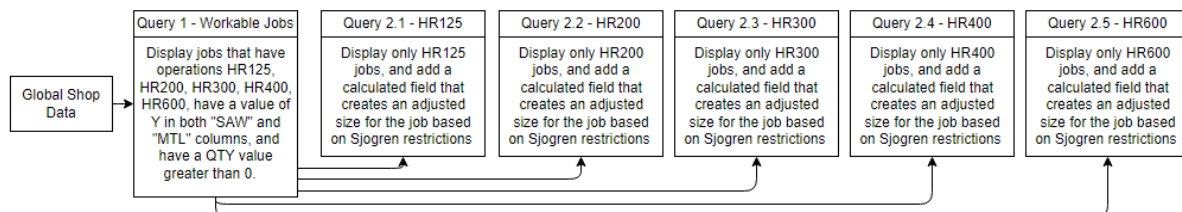


Figure 4.2 – A logical flow diagram detailing the functions of the six queries used to deliver filtered information to Microsoft Excel.

4.4.2.2 Linking Microsoft Access to Microsoft Excel

In our Microsoft Excel workbook, we created one blank spreadsheet for each Operation. These blank spreadsheets were populated with data coming directly from our Microsoft Access database, accomplished by using Microsoft Excel’s link data feature. This feature creates a table in the target spreadsheet using data from a user-specified Microsoft Access database object, which in our case is a query. This table is refreshed and updated every time the Microsoft Excel file is opened, according to Sjogren’s needs, to sync up with any changes made to the source data by Global Shop throughout the day.

Microsoft Excel’s Power Query Editor was used to append a column labeled “Index” to the imported data, which assigned a number to each imported row, starting at one and incrementing by one.

4.4.2.3 Microsoft Excel

4.4.2.3.1 Defining Components of the Models

Our solution consists of 5 nearly identical optimization models, each pertaining to a specific Operation. The only significant difference between these models is the number of faces available for each Operation, and our definitions are generalized to each model unless otherwise stated. To create these models, we first listed out their objective functions, decision variables, and constraints:

The **objective function** seeks to maximize hours of machine run time, calculated by summing the hours required for completion for the selected jobs. This can be expressed mathematically as:

$$Max = \sum_{i=1}^n h_i$$

h represents each job’s hours, i represents the current job being summed, and n represents the total number of jobs.

The **decision variables** are the Index numbers of jobs, which are assigned automatically using Microsoft Excel’s power query editor on imported Operation data. Solver deals with only numerical values, rather than Sjogren’s text-based job names, so assigning our imported jobs

index numbers starting at one allows for Solver to test quickly. These indices were chosen over the provided job numbers for two reasons: (i) our index numbers are significantly smaller than Sjogren's job numbers, which begin in the 200,000's. Had we used existing job numbers as an index, computational time would increase and complicate constraints. (ii) Sjogren's job numbers are presently formatted as text values, which are incompatible in Solver.

The first **constraint** ensures that the Tombstone Load Height, calculated by summing the material height for the selected jobs, of one face must be less than or equal to the tombstone's height of 23 inches. This can be denoted as:

$$S. T. \sum_{i=1}^n x_i \leq 23$$

x represents the part height of each job's material. This constraint is per face, meaning that additional faces must each have a load height summing to less than or equal to 23 inches.

Our second constraint ensures that we may only use a decision variable, or job, once across all possible faces. For example, if a single HR400 job can be machined on two faces, it must only appear on one face in the model.

4.4.2.3.2 Building the Models

Each of our 5 models work with 2 spreadsheets: one spreadsheet containing data imported from Microsoft Access, which follows the naming convention [Operation] Jobs, and another spreadsheet focused on Solver, which follows the naming convention [Operation] Calculator.

Within each Calculator spreadsheet, designated cells were created for the objective function, decision variables, and constraints required by the model (Figure 4.3).

The screenshot displays a complex spreadsheet with the following components:

- Constraints Table (Rows 2-4):**

Constraint	Value	Operator	Limit	Unit
Tombstone Load Height 1	19	<=	23	inches
Tombstone Load Height 2	21	<=	23	inches
- Objective Function (Row 5):** Maximize Objective Function Total Hours = 13
- HR400 Optimal Jobs Table (Rows 6-10):**

HR400 Optimal Jobs					
Face 1			Face 2		
Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length
P	1	6.5	F	1	8.5
200015	9	7.125	200010	11	2.625
			200004	16	2.75
- Decision Variable Cells:** Cells in columns B, C, D, E, F, G, H, I, J, K, L, M, N, O are colored yellow.
- Navigation Bar (Bottom):** Optimal Jobs Overview | HR400 Calculator | HR400 Jobs | HR125 Calculator | HR125 Jobs | HR600 Calculator | HR600 Jobs | HR200 Calculator | HR200 Jobs

Figure 4.3 – The HR400 Calculator spreadsheet in Deliverable 2, with all components visible.

Decision variable cells are colored yellow, as seen in Figure 4.4, and are given their own column per face available for an Operation, leaving 3 columns between each decision variable column for the display of attributes. The number of decision variables per column varies depending on the total number of tombstone faces available for that Operation. This varying number is due to Solver having a maximum of 200 decision variables, and can be calculated by dividing 200 by the number of available faces. Using HR400 and its 2 available faces as an example, 2 decision variable columns would be created, each with 100 decision variables, for its model. Models with uneven faces have their decision variable numbers rounded down for consistency.

The objective function cell (Figure 4.6) displays the sum of the “hours required for job completion” attributes for each face in the model.

Maximize Objective Function Total Hours	13
------------------------------------------------	-----------

Figure 4.6 – Objective Function cell displaying the maximum hours of job run time for the HR400 Calculator spreadsheet.

The constraint cells for Tombstone Load Height in each model pertain to one face only; one column of decision variables warrants one constraint cell. These constraint cells display the sum of the “height in inches” attribute for their specific face, and each must be less than or equal to 23 inches (Figure 4.7).

P	Q	R	S	T
Constraints				
Tombstone Load Height 1	19	<=	23	inches
Tombstone Load Height 2	21	<=	23	inches

Figure 4.7 – Constraint cells displaying the total raw material height for each tombstone for the HR400 Calculator spreadsheet.

The constraint dictating the single use of a decision variable is determined by first displaying a list of index numbers used by an Operation, which is taken directly from the Index column in the Job spreadsheet. To the right of each item in this list of index numbers is a cell containing a SUM function. The SUM function sums the two yellow decision variables in a row. This value must be less than or equal to one, to indicate a job is being used either once or not at all. Figure 4.8 shows these columns.

	A	B	C	D	E	F	G	H
1	<u>1</u>	0	+	0	=	0	<=	1
2	<u>2</u>	0	+	1	=	1	<=	1
3	<u>3</u>	1	+	0	=	1	<=	1
4	<u>4</u>	1	+	0	=	1	<=	1
5	<u>5</u>	0	+	1	=	1	<=	1
6	<u>6</u>	0	+	1	=	1	<=	1
7		0	+	0	=	0	<=	1
8		0	+	0	=	0	<=	1
9		0	+	0	=	0	<=	1
10		0	+	0	=	0	<=	1
11		0	+	0	=	0	<=	1
12		0	+	0	=	0	<=	1
13		0	+	0	=	0	<=	1
14		0	+	0	=	0	<=	1
15		0	+	0	=	0	<=	1
16		0	+	0	=	0	<=	1
17		0	+	0	=	0	<=	1
18		0	+	0	=	0	<=	1
19		0	+	0	=	0	<=	1
20		0	+	0	=	0	<=	1
21		0	+	0	=	0	<=	1

Figure 4.8 – Constraint cells that prevent repeated decision variable from occurring for the HR400 Calculator spreadsheet.

Another designated cell area called “[Operation] Optimal Jobs” was created in each material calculator to output the list of jobs that need to be completed for jobs associated with that material (Figure 4.9). This is used in junction with the Optimal Jobs Overview worksheet, which will be covered in the next section.

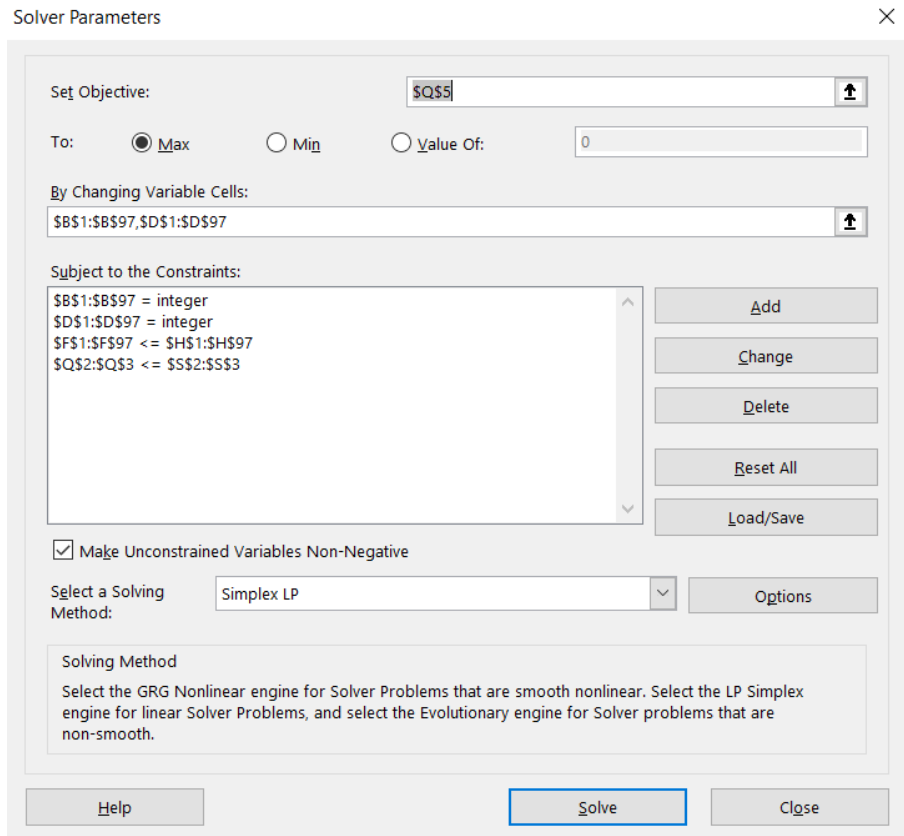


Figure 4.10 – Solver parameter window for the HR400 Calculator spreadsheet, filled with appropriate cell references required to successfully run optimization calculations.

To streamline this process, we have implemented a user-friendly VBA macro to replicate Solver's functionality at the push of a VBA button (Figure 4.11). Upon activation, this macro specifies the unique objective function cell, decision variable cells, and constraint cells location for each of the 5 models present in the workbook, and solves the models one at a time. After solving, the job number attributes are automatically displayed on a spreadsheet titled Optimal Jobs Overview.

From the Optimal Jobs Overview spreadsheet, the Foreman asked us to list the raw material size associated with a specific job number. Therefore, the IF function is used to display the raw material size of the jobs specified. This value is determined by searching for a listed job number in an Operation's Job spreadsheet table, and returning the corresponding raw material size.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V										
1																																
2		OPTIMIZE																														
3																																
4		Tombstone 1										Tombstone 3																				
5		Face 1 - HR200					Face 2 - HR300					Face 3 - HR300					Face 4 - HR300					Face 1 - HR125			Face 2 - HR200			Face 3 - HR600				
6		Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	
7		200001	1	7.125	J	1	5.75	E	1	8.5																						
8		200002	10	3.75	O	8	5	200003	11	2.125																						
9		200007	16	3.5	200011	15	4.75																									
10																																
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20																																
21																																
22																																
23		Tombstone 2										Tombstone 4																				
24		Face 1 - HR400					Face 2 - HR400					Face 1 - HR125					Face 2 - HR200					Face 3 - HR600										
25		Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	Job	Stop #	Saw Cut Length	
26		P	1	6.5	F	1	8.5	B	1	6.00005	I	1	7.5	C	1	6.000001																
27		200015	9	7.125	200010	11	2.625																									
28					200004	16	2.75																									
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Figure 4.11 – Optimal Jobs Overview spreadsheet containing the total number of jobs that need to be run for each tombstone, and on which face.

5.0 Results and Analysis

5.1 Deliverable 1

5.1.1 Okuma Multus Work Backlog

Prior to the implementation of Deliverable 1, our team was made aware by the foreman that a mechanical breakdown had occurred on the Okuma Multus on November 8th, 2023. This breakdown was not fully repaired until January 5th, 2024. During this time, the Okuma accumulated a backlog of approximately 600 job-hours, which should be considered when viewing our final results.

5.1.2 Implementation

Implementing Deliverable 1 required the use of Sjogren's computers, which provide direct access to their databases and servers.

To avoid any implementation problems and use our limited time on-site efficiently, we reached out to the foreman via email to confirm the names of columns currently used in the database and the current datatypes of those columns. Once we received confirmation, we tested implementation in a new, blank Microsoft Access database. During this test implementation, we were able to work out all errors and bugs that were present in our code, and sent an email to the foreman containing the SQL code for both queries.

Upon arrival at Sjogren Industries for implementation, our team sat down at the foreman's desk, where we were granted access to the email we had sent prior to our meeting and Sjogren's Microsoft Access database for the Okuma Multus. We were able to successfully implement the first query after altering our placeholder names for the table we were taking data from. The second query required brief troubleshooting, but also executed error-free after minor code editing.

After running our optimization query, we manually calculated the optimal jobs displayed to verify our code was correct when applied to the actual database. We confirmed our code worked, showed our work to the foreman, and asked for overnight production hour data in the future for comparisons.

5.1.3 Results

After implementation of the Microsoft Access queries, we asked the foreman to use the optimization model and send us data for the Okuma’s unattended hours *after* implementation to compare against the unattended hours before implementation. We used the same time frame for comparison. Over the weeks that data was being gathered, our team exchanged emails with the foreman, inquiring about any errors that the program may have faced, operational errors, and questions Sjogren may have. The foreman reported no such incidents, and soon provided us with the requested information. Table 5.1 shows a summary of the unattended hour data we received for the Okuma during 2023 and 2024, during six weeks spanning from January to February.

Table 5.1 – A comparison of the Okuma’s unattended hours for six weeks in 2023 versus 2024 and the total hours completed during the six weeks in each year.

Week	2023 Unattended Hours	2024 Unattended Hours	% Increase
1/8 thru 1/14	49	72.5	48%
1/15 thru 1/21	38	96	153%
1/22 thru 1/28	41.5	106.25	156%
1/29 thru 2/4	79.75	86	8%
2/5 thru 2/11	75.5	70.5	-7%
2/12 thru 2/18	49	49.5	1%
Total	332.75	480.75	44%

While the table shows an approximate 44% increase in unattended hours for the six weeks, from 332.75 hours in 2023 to 480.75, we note that this figure needs to be interpreted with caution. Notably, in 2024 operations had to account for the 600-job hour backlog. As shown in Table 5.1, the initial weeks of implementation demonstrate a significant increase in unattended hours, something very positive. Regarding this backlog, the foreman had the following to say in an email written to our team:

“...We were able to knock out the backlog in quick fashion by utilizing unattended operation. We were able to optimize the machine operation using the program developed for this project. It allowed us to run the longest jobs at night and on the weekends maximizing hours available. We had achieved keeping the machine running 48 hours over the weekend...” (Collette).

This email indicated that Deliverable 1 was not only able to successfully utilize 100% of Sjogren’s weekend hours, but also complete approximately 2 months of backlog in roughly 3 weeks. However, the final two weeks of our monitoring do not have results which are as positive. This quick completion of backlog led to 5 less unattended hours during the week of 2/5 thru 2/11 in 2024 compared to 2023, which suggests two possibilities: (i) Sjogren has received less orders during that week in 2024 than in 2023 or (ii) that our program has completed all available jobs during that week in 2024.

Overall, Deliverable 1 shows promise. We developed a way to automate scheduling of unattended hours. While our approach may not replace decades of expertise, it does provide a method to schedule jobs when that expertise is not available. Because of time constraints, we were unable to conduct extensive testing; however, the monitoring we were able to conduct illustrated that our approach was able to reduce a 600-job hour backlog in three weeks.

5.2 Deliverable 2

5.2.1 Implementation

Deliverable 2 followed a similar implementation process to Deliverable 1, requiring the use of Sjogren’s computers, which provide direct access to their databases and servers. One key difference between these approaches is that we would also need to use the Microsoft Excel Application on the Sjogren computer for model implementation.

Prior to implementation, we tested implementation by creating a new Microsoft Access database using sample data, and using a copy of our existing Microsoft Excel model workbook. During this test implementation, we became more familiar with the process of connecting Microsoft Excel to Microsoft Access to retrieve data, and simulated how Sjogren would view our final workbook. Most importantly, we learned that the imported data tables from Microsoft Access caused many cells in the models to return error values, which we were able to fix by connecting each cell to the newly imported data table. Understanding this key issue, our team would be able to implement our program more quickly when needed.

On implementation day, our team emailed the foreman a copy of our Microsoft Excel workbook and VBA code. We sat down at the foreman's desk, where we were granted access to the emails we had sent prior and Sjogren's Microsoft Access database for the Matsuura H-Plus 300. Due to the simplicity of the Microsoft Access database queries we used for Deliverable 2 and our familiarity with Sjogren implementation, we were able to write our queries directly in the Sjogren database without needing to refer to emails. After creating the Microsoft Access database queries, our team then downloaded the Microsoft Excel file we emailed to Sjogren to the computer, and connected the newly created query information to the workbook. While tedious, connecting the database information to the workbook was a success and immediately returned "optimal" results from Sjogren's Global Shop data.

To conclude that these results were truly optimal, our team manually calculated the optimal jobs for each tombstone face to verify that our model was correct after being connected to Sjogren's database. We confirmed our program worked, showed our work to the foreman, and asked for overnight production hour data in the future for comparisons.

5.2.2 Results

Due to the time constraints of the MQP, our team was unable to obtain data for the Matsuura's unattended hours after implementation. Our team has arranged to speak with the foreman to obtain data for analysis beyond our MQP, to ensure the quality of Deliverable 2.

Considering the similarities between Deliverables 1 and 2, the robustness shown during testing by Deliverable 2, and how overnight jobs for the Matsuura are currently by loaded by size rather than job-hours, our team anticipates a more drastic increase in unattended hours for the Matsuura than the Okuma in a similar time period.

6.0 Conclusion and Recommendations

6.1 Introduction

Our team's goal was to provide Sjogren with tools that would increase their overnight utilization of the Okuma Multus and Matsuura H-Plus 300 machines while being simple to both understand and integrate into their existing work environment. With the help of Sjogren staff and our resourceful use of Microsoft Excel and Microsoft Access, two highly utilized and well-known applications within Sjogren, we were able to successfully increase the Okuma's overnight utilization while anticipating a higher rate of overnight utilization for the Matsuura.

Despite these achievements, it is important to acknowledge the limitations present within our solutions and provide Sjogren recommendations on how to address these limitations. For the remainder of this section, we first detail the limitations for each deliverable, and end with general recommendations.

6.2 Deliverable 1

Microsoft Access is designed to handle very large amounts of data, and as such our team does not anticipate any scaling issues occurring with Deliverable 1 should Sjogren Industries grow in the future.

However, during implementation we did observe calculation times of up to 3 minutes for Deliverable 1, which we attribute to hardware onsite. We noted that these issues were not present on our team's computers when we ran the tool for Deliverable 1. As a result, our team recommends improvements to existing Sjogren hardware that will be utilizing Deliverable 1 to reduce calculation times, particularly if Sjogren Industries is considering growth opportunities or comparing a large number of jobs at once.

6.3 Deliverable 2

The usage of Microsoft Access for Deliverable 2 poses less issues than Deliverable 1, as no calculations are being performed. This indicates that Deliverable 2's queries could handle as many jobs as Sjogren desires without slowing down, but the same cannot be said for Deliverable 2's Microsoft Excel file.

One of the key limitations with the Solver Add-In in Microsoft Excel is that the application can only handle up to 200 decision variables and up to 100 constraints

simultaneously; if either one of these values is exceeded, Solver will be unable to determine the optimal solution. Deliverable 2 deals with this limitation by using the maximum number of decision variables possible for each set of Operations, where Operations spread across 2 total faces have models with 97 decision variables per face (to account for 97 decision-variable based constraints and 3 general constraints) and Operations spread across 3 total faces have models with 66 decision variables per face. Our team does not anticipate any immediate issues with these models, since rigorous filtering done by our Microsoft Access queries typically returns well below 66 possible jobs per Operation. Yet, it is feasible that the Matsuura can break down and generate its own backlog, in which case our models would be unable to function with the amount of data provided.

To compensate for this limitation, our team proposes the use of OpenSolver, a Microsoft Excel VBA Add-In that has the same capabilities as Microsoft Excel's existing Solver. This software, which can be downloaded online, allows for an infinite number of decision variables and constraints, granting unlimited scaling should Sjogren require it. OpenSolver was not used in our project because of downloading and firewall restrictions.

If Sjogren implements OpenSolver into the existing workbook, all columns present in the [Operation] Calculator worksheets would need to be infinitely extended downwards to reach the bottom of the booklet, to cover the maximum potential number of jobs. Second, a cell would need to be added that counts the total number of jobs imported into the [Operation] Jobs worksheet; this cell would be referenced by an updated VBA script that uses it as a dynamic variable. This dynamic variable would indicate the endpoint of the range of decision variables and the endpoint of the range of constraints, and would be unique to each model. Finally, the Tombstone Load Height [X] cells, Objective Function cells, and job filtering cells under the [Operation] Optimal Job cells would need to be expanded to include the entirety of the columns they refer to. With these changes, Deliverable 2 will be able to scale infinitely with Sjogren, limited only by hardware calculation speeds and assuming that tombstone faces stay the same.

If Sjogren wishes to add more Operations to the workbook, they would first need to copy one of our existing queries in their Microsoft Access Database, and specify the Operation they wish to add in the "Criteria" section of the query design. After this, Sjogren would need to create an [Operation] Jobs spreadsheet and connect it to the newly created query for the desired

Operation. Next, an [Operation Calculation] spreadsheet would need to be created by copying an existing spreadsheet that contains the desired number of available faces for the operation, which is currently two or three faces. If more faces are desired, they can be created by following the existing conventions in place for decision variables, attributes, and constraints. However, we strongly advise against creating more than three faces unless OpenSolver is used, as the number of faces directly corresponds to the number of decision variables, which are limited in Solver. With the desired number of faces, cells pertaining to the [Operation] Jobs datasheets will need to be altered to reference the newly implemented Operation.

Finally, the VBA button code would need to be updated to run on the newly created spreadsheets by copying code for existing spreadsheets and following their formatting. Most importantly, the newly created dynamic variable cell must be used by the script to limit decision variables on each model according to the number of jobs available for the Operation. This would be accomplished by having the VBA code read the contents of the cell, write those contents to a variable as text, and concatenate that variable to the end of existing text that indicates the start of an array.

6.4 General Recommendations

An overall recommendation would be to adhere to Microsoft-suggested data formats. Microsoft Access allows users to input data types when creating columns for data storage, such as AutoNumber, Short Text, Number, Date/Time, and more. These data types must be manually set by the database creator, and can only be altered in tables; a data type cannot be transformed in a query. The default data type setting for the first column is the AutoNumber data type, and all following columns default to the Short Text data type. Furthermore, it is possible that changing a data type in a table may cause existing queries to malfunction, or alter existing data in the table itself. Therefore, it is critical to select the appropriate data types and adhere to data naming conventions set in place by the database creator.

Currently, Sjogren largely follows these Microsoft data format guidelines as seen in Date columns being stored in the Date/Time data type or Operations being stored as Short Text data types. However, some columns do not match their anticipated data type. For example, Sjogren uses Job Number, which is typically a six-digit value, but it is stored as a Short Text data type.

In our test database for Deliverable 1, a “tiebreaker” system was introduced to eliminate the return of errors in the event a material had two identical jobs competing for the highest value sub-spindle collet slot. This tiebreaker system selected the lowest Job Number between the tied jobs, and displayed that as the winner – that is the job that should be scheduled. Upon implementation, our code failed to run because Sjogren stores the Job Number data as Short Text, and SQL code cannot perform mathematical operations on text. We incorrectly assumed that the numerical data in Job Number would be stored as the Number data type. Attempts to change the data value directly in Sjogren’s table were prohibited due to administrator-level controls placed on the database. As a workaround, the code was modified to treat the Job Number as text, now sorting it from the smallest value first with the Ascending order type. With the change, the code now behaved as it did in the test database.

Our recommendation is that, when sufficient time is available, Sjogren should go through their databases and observe their data types, ensuring that data that is solely numerical has the Number data type, and other columns follow similar logic. With these changes, future implementation or work performed within or using Sjogren’s databases will be more streamlined and easier to work with.

7.0 Project Reflections and Discussion

7.1 Introduction

Although our goal for Sjogren was to reduce downtime on machines capable of running unattended, the goals of a Major Qualifying Project are more than just numerical analyses. We were asked to create an engineering design process while working as a team. This section provides our reflections on what we learned during this project.

7.2 Design

The first step in our design process was to identify and define a problem statement. Our problem statement was loosely defined in the beginning of the project, when Sjogren stated that significant machine downtime and reliance on manual job scheduling was a concern. From this, we brainstormed solutions that would not only solve Sjogren's issues but would also fulfill the requirements for the Major Qualifying Project. We decided to create tools specific to each machine that would optimize Sjogren's job scheduling. We analyzed the data post-implementation to derive recommendations for Sjogren moving forward and for any students that would continue this project in the future.

7.3 Constraints Considered and Broader Impact

Safety as a constraint is a high priority, specifically regarding unattended machining overnight. When dealing with unattended machines, it is imperative that jobs being run do not risk damaging the machine. Sjogren's safety limitations on space between raw materials on tombstone faces in the Matsuura directly impacted how our team conducted the calculations for Deliverable 2's optimal jobs.

Scalability was also a heavily considered constraint throughout the duration of this project. Our team focused on crafting a solution for the long term, which could handle far more data than what Sjogren is currently processing. The prospect of Sjogren's growth influenced our use of Microsoft Access as the sole software for Deliverable 1, and Deliverable 2 being completed using the maximum possible number of decision variables possible while being ready for OpenSolver integration.

Socially, our team did not want to disrupt the current culture of Sjogren by introducing a new complicated tool or software to daily operations. This directly influenced our decision to

build upon Sjogren's existing use of Microsoft Access and Microsoft Excel, and how we designed each deliverable to be as easily understood and used as possible.

In a broader context, our design process and project should directly impact Sjogren economically. Our design process provides groundwork for Sjogren should they wish to optimize other machines in their facilities using similar methods. By maximizing unattended hours through our project, Sjogren should see shorter order fulfilment times and increased throughput, getting more out of their existing resources. Our design process and project may also hold a global impact, achieved through Sjogren's existing global customer base, competitors, and distributors. Sjogren's strategic integration of aspects of our design process or our deliverables into other facilities could propel Sjogren further ahead of their competitors, and may drive further innovation in the wire tooling industry.

7.4 Experience Acquired and Applying New Knowledge

7.4.1 Conor

Over the course of our project, we gained a lot of knowledge and experience in real-world scenarios and industry. The biggest takeaway that I personally received were communication and organization skills. Having to schedule meetings to talk with the Foreman most weeks to ask the right questions was essential for our deliverables and report. We also had to schedule meetings with our project advisor which further developed my organization and communication skills.

I also learned a lot more about Microsoft Excel's Solver tool and VBA macros through the development and design of our deliverable 2.

7.4.2 Henry

This project made a big impact on me both as a student, but also as a professional in the workplace. Here at WPI, our coursework has many advantages to it, such as the on-hand experiences of labs, projects, and other groupwork. Since our school is based off teamwork, collaboration, and real-world applications, it makes it a bit easier to work with a company who is a global leader in manufacturing in its industry. However, there really is never enough experience you can gain in a classroom to prepare you to work with a real company with actual

data, deadlines, circumstances, employees, customers, and needs. So, working with Sjogren was quite the learning curve all throughout our time working with them over the course of this year.

The realization of the reality of the project set in during our first meeting with the foreman, when he was explaining the company and what our project would be. We were all a bit puzzled at first. However, like with any other new situation, the more time we spent at the company, meeting with the foreman and learning more about the company, the more we felt comfortable being there, learning what our project was, and figuring out a plan of action. Throughout this project, I learned many skills and knowledge of industrial work that will prove influential throughout my life.

One of the most important things I learned was communication. Being able to communicate effectively with the foreman was well as our advisor and groupmates was essential. Also, learning a bit of Microsoft Access and how a company may use it through observing groupmates' usage with it as well as company files was very interesting. Furthermore, learning more about the company and how they operate in terms of how an order is received to it being manufactured and out the door and all the steps in between was fascinating. It really puts things into perspective as to what happens behind the scenes at a company, as well as how products are made.

This project was truly an amazing experience, and I am thankful to have been given the opportunity to participate in this endeavor. The skills and concepts I learned through this real-world experience will prove invaluable throughout the early stages of my career and they will help me to better understand the ins and outs of a company.

7.4.3 Christian

The value of asking questions and taking notes is not taught explicitly at WPI, but was the most prominent experience I gained during this project. The learning process was trial and error; after our very first site visit, I was highly confused on the briefing we received of Sjogren's facility because I did not ask enough questions when I was lost. At subsequent site visits, when I failed to grasp concepts or systems after being informed, I asked as many questions as possible and took notes—one site visit consisted of approximately 45 minutes of asking questions to understand all relevant aspects of the Matsuura H-Plus 300. When sitting down to work on our deliverables or this report, detailed notes kept our team focused on completing our

project, rather than sending out emails and waiting for answers to specific questions as they came up.

On a technical level, I became more familiar with the limitations of Microsoft Excel's Solver tool during the creation of Deliverable 2 through testing and research. When initially working on this project, our team was unable to use the LP Simplex or GRG Non-Linear optimization engines in Solver because our Microsoft Excel calculator spreadsheets utilized IF, COUNT, and XLOOKUP functions directly in the calculations of the objective function. My research revealed that Microsoft Excel considers these functions as discontinuous functions, which inhibit the use of LP Simplex or GRG Non-Linear engines. These spreadsheets were able to run Solver, however, with the Evolutionary engine. During testing, we received inconsistent results from the Evolutionary engine, and I researched why. The Evolutionary engine is unable to determine an optimal solution because it does not rely on derivative or gradient information, instead randomly inputting decision variables and stopping after a certain amount of time. Our project became stuck, because the discontinuous functions used were critical to retrieving imported data from Global Shop, and displaying optimal jobs after calculating. In a dream-like epiphany I was able to draw on my prior research and remove the discontinuous functions from the objective function calculations, using the discontinuous functions to only display the calculated optimized jobs. By separating out the discontinuous functions, I was able to develop a set of constraints that enabled Solver to use the LP Simplex engine.

7.5 Teamwork

As a team, we possess diverse strengths, weaknesses, experiences, and goals. Our team leveraged these individual talents to complete this project with high quality and effectiveness. Each team member held a leadership role in their own area of the project based on their strengths, where each area collaborated with all three team members.

Christian led the general creation and implementation of Deliverables 1 and 2 using his technical experience with Microsoft Access and Microsoft Excel, and organized project goals and milestones based on the progress of the deliverables.

Conor led the development and implementation of the VBA scripting for Deliverable 2 with his VBA coding experience and organized team meetings with our advisor.

Henry led the creation of presentations and posters for our project and the coordination between our team and Sjogren by organizing site visits and following up on data requests.

Within these areas, our team discussed and provided insight on each other's work and supported other team members when they needed help with completing tasks.

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Appendices

Appendix A – Global Shop Job List and Machine Tables

A-1 Global Shop Job List

WO	JOB	SUFFIX	PART	PRODUCT_LI	ROUTER	DESCRIPTION	QTY_ORDER	QTY_COMPL	DATE_OPEN	DATE_DUE	DATE_CLOSE	Click to Add
100200-001	100200	001	D-2004232	SB	D-2004232-01	BURNER SIDE T	1	1	12/27/2005	1/9/2006	1/13/2006	
100200-002	100200	002	D-2005168	SB	D-2005168-01	TRANSITION TO	1	1	12/27/2005	1/12/2006	1/12/2006	
100248-001	100248	001	E-41907	SB	E-41907	TIRE ROLL UNIT	40	39	1/10/2006	3/4/2006	3/31/2006	
100249-001	100249	001	61601-C	SB	61601-C	LEAD SCREW -	3	2	1/10/2006	2/6/2006	3/17/2006	
100267-001	100267	001	STUD FOR TR32	PS	STUD FOR TR32	GUARD SUPPO	200	400	1/16/2006	1/24/2006	1/24/2006	
100267-004	100267	004	STUD FOR TR40	PS	STUD FOR TR40	GUARD SUPPO	100	200	1/16/2006	1/24/2006	1/24/2006	
100275-001	100275	001	108169-40	GR	108169-40	GR-32 W/RAD C	120	240	1/24/2006	2/3/2006	2/24/2006	
100275-002	100275	002	108547-48		108547-48	GR245 W/RAD C	100	200	1/24/2006	2/3/2006	2/24/2006	
100276-000	100276	000	406059-01		406059-01	507 RH HORIZO	1	1	1/24/2006	2/3/2006	1/26/2006	
100278-000	100278	000	IS-715A-LH-SP1		IS-715A-LH-SP1	715A-LH W/ RE	1	1	1/18/2006	3/3/2006	3/31/2006	
100278-001	100278	001	108069-78		108069-78	R2ZZ W/ RECT C	14	14	1/18/2006	4/11/2006	3/16/2006	
100278-002	100278	002	108069-82		108069-82	R2ZZ W/ RECT C	10	10	1/18/2006	4/11/2006	3/16/2006	
100284-001	100284	001	B-97061	SB	B-97061	0 PLUG RING - 4	1	1	1/13/2006	1/20/2006	1/27/2006	
100327-001	100327	001	IS715A-LH-SPEK		IS715A-LH-SPEK	715A-LH W/PLA	1	1	1/24/2006	1/22/2006	1/26/2006	
100328-000	100328	000	EC45-7HX5V-2F	EC	EC45-7HX5V-2F	EC45-7HX5V-2F	1	2	2/7/2006	3/31/2006	4/27/2006	
100436-001	100436	001	631691E	SB	631691E	1600 TON RYPL	2	2	2/6/2006	3/10/2006	3/17/2006	
100436-002	100436	002	631690D	SB	631690D	1600 TON RYPL	1	1	2/6/2006	3/10/2006	3/17/2006	
100437-001	100437	001	C-406501	SB	C-406501	DRAWBAR, G&	1	1	2/6/2006	5/3/2006	4/10/2006	
100445-001	100445	001	D-2001026	SB	D-2001026	END NOSE RING	3	3	2/7/2006	2/24/2006	3/17/2006	
100500-001	100500	001	AH-2153	A SB	AH-2153	A RESV. INDICAT	25	25	2/16/2006	3/1/2006	3/2/2006	
100508-001	100508	001	C-6077	SB	C-6077	ENCODER SHAF	1	1	2/17/2006	3/3/2006	3/17/2006	
100508-002	100508	002	D-5953	SB	D-5953	SHAFT, DRIVEN	1	1	2/17/2006	3/3/2006	3/31/2006	
100508-003	100508	003	D-5954	SB	D-5954	DRIVE SHAFT	1	1	2/17/2006	3/3/2006	3/17/2006	
100520-001	100520	001	DH-1030#10X6F	SB	DH-1030#10X6F	FINISH HONE I	2	2	2/21/2006	2/22/2006	2/20/2006	
100543-002	100543	002	631690D	SB	631690D	1600 TON RYPL	1	1	2/28/2006	4/1/2006	3/17/2006	
100544-001	100544	001	WP.5485612-03	SB	WP.5485612-03	BLADE CLAMP,	1	1	2/28/2006	4/5/2006	3/27/2006	
100546-001	100546	001	631691E	SB	631691E	1600 TON RYPL	2	2	2/28/2006	4/1/2006	3/17/2006	
100572-001	100572	001	D-98133	SB	D-98133	0 PLENUM WATE	3	3	2/28/2006	3/21/2006	3/17/2006	
100572-002	100572	002	D-98140	SB	D-98140	0 OUTER PLATE,	2	2	2/28/2006	3/21/2006	3/8/2006	
100572-003	100572	003	C-92014	SB	C-92014	2 WATER PLENUM	3	3	2/28/2006	3/21/2006	3/17/2006	
100607-001	100607	001	F-1018.06.1.F3	SB	F-1018.06.1.F3	JAWS - SPEED T	3	3	3/6/2006	6/4/2006	5/11/2006	
100608-001	100608	001	F-1018.06.1.F1	SB	F-1018.06.1.F1	DRAWBAR - SP	2	2	3/6/2006	4/29/2006	6/9/2006	
100609-001	100609	001	WP.5485612-04	SB	WP.5485612-04	BLADE CLAMP,	1	1	3/6/2006	6/29/2006	3/27/2006	
100623-001	100623	001	92351-15159-0C	SB	92351-15159-0C	HAND FORGINC	2	2	3/7/2006	3/17/2006	3/17/2006	
100625-001	100625	001	92351-15171-0C	SB	92351-15171-0C	HAND FORGINC	63	63	3/7/2006	3/17/2006	3/17/2006	
100672-001	100672	001	DH-1030#10X6F	SB	DH-1030#10X6F	FINISH HONE C	8	8	3/16/2006	3/24/2006	3/22/2006	
100676-001	100676	001	C-406501	SB	C-406501	DRAWBAR - G8	1	1	3/16/2006	4/7/2006	4/10/2006	

Figure A-1 – A screenshot of a table in Sjogren’s Microsoft Access database which displays all jobs imported from Global Shop

A-2 – Okuma Multus Machine Table

PROVEN PRGM	MATERIAL	STOCK LENGTH	OUT	DATE_DUE	JOB	SUFFIX	SEQ	ROUTER	RSEQ	R	QTY	HRS REM	PERATT	SAW	MATL	TOMBSTONE	FACE	STOP	PROGRAM NAME
Y	A2R1.250		3	01-Nov-23	250142	000	000200	206524-00	000300		0	0						NO	FEED MODE
				01-Nov-23	250142	000	000210	206524-00	000300		1	4.5						NO	FEED MODE
	C12L14R1.625		2.5	12-Oct-23	250185	000	000200	106930-00	000300		0	0					YES	1/2"	SUB SPINDLE MODE
				12-Oct-23	250185	000	000210	106930-00	000300		5	36					YES	1/2"	SUB SPINDLE MODE
				12-Oct-23	250183	000	000200	106928-00	000300		0	0					YES	1/2"	SUB SPINDLE MODE
				12-Oct-23	250183	000	000210	106928-00	000300		4	26.4					YES	1/2"	SUB SPINDLE MODE
				16-Oct-23	250186	000	000210	106931-00	000300		4	16.008					YES	1-1/8"	SUB SPINDLE MODE
				16-Oct-23	250186	000	000200	106931-00	000300		0	0					YES	1-1/8"	SUB SPINDLE MODE
			3	09-Oct-23	250075	000	000210	119836-02	000200		8	60					NO		FEED MODE
				09-Oct-23	250076	000	000200	119836-03	000200		0	0					NO		FEED MODE
				09-Oct-23	250076	000	000210	119836-03	000200		8	60					NO		FEED MODE
				09-Oct-23	250075	000	000200	119836-02	000200		0	0					NO		FEED MODE
				09-Oct-23	250074	000	000200	119836-01	000200		0	0					NO		FEED MODE
				09-Oct-23	250074	000	000210	119836-01	000200		8	60					NO		FEED MODE
				12-Oct-23	250184	000	000210	106929-00	000300		3	23.994					YES	1/2"	SUB SPINDLE MODE
				12-Oct-23	250130	000	000210	119821-00	000200		4	40.8					YES	1"	SUB SPINDLE MODE
				12-Oct-23	250130	000	000200	119821-00	000200		0	0					YES	1"	SUB SPINDLE MODE
				12-Oct-23	250184	000	000200	106929-00	000300		0	0					YES	1/2"	SUB SPINDLE MODE
				13-Oct-23	250178	000	000200	102129-01	000400		0	0					YES	3/4"	SUB SPINDLE MODE
				13-Oct-23	250178	000	000210	102129-01	000400		9	54					YES	3/4"	SUB SPINDLE MODE
				13-Oct-23	250036	000	000210	227583-01	000400		3	23.994					NO		FEED MODE
Y	C12L14R1.625		3	13-Oct-23	250036	000	000200	227583-01	000400		0	0					NO		FEED MODE
				13-Oct-23	250035	000	000210	227582-01	000400		3	23.994					NO		FEED MODE
				13-Oct-23	250035	000	000200	227582-01	000400		0	0					NO		FEED MODE
			3.75	19-Oct-23	250179	000	000200	102129-02	000400		0	0					YES	3/4"	SUB SPINDLE MODE
				19-Oct-23	250179	000	000210	102129-02	000400		3	14.994					YES	3/4"	SUB SPINDLE MODE
			4	13-Oct-23	250037	000	000200	228219-00	000200		0	0					YES	1/2"	SUB SPINDLE MODE
				13-Oct-23	250037	000	000210	228219-00	000200		6	43.2					YES	1/2"	SUB SPINDLE MODE
	C12L14R2.500		1.5	16-Oct-23	250195	000	000310	206929-00	000500		4	19.992					YES	3/4"	SUB SPINDLE MODE
				16-Oct-23	250195	000	000200	206929-00	000400		0	0					YES	3/4"	SUB SPINDLE MODE
				16-Oct-23	250195	000	000300	206929-00	000500		0	0					YES	3/4"	SUB SPINDLE MODE
				16-Oct-23	250195	000	000210	206929-00	000400		4	48					YES	3/4"	SUB SPINDLE MODE
				18-Oct-23	250196	000	000200	207016-00	000300		0	0					YES	5/8"	SUB SPINDLE MODE
				18-Oct-23	250189	000	000200	106935-00	000300		0	0					NO		FEED MODE
				18-Oct-23	250189	000	000210	106935-00	000300		10	70.02					NO		FEED MODE
				18-Oct-23	250196	000	000250	207016-00	000300		4	100.8					YES	5/8"	SUB SPINDLE MODE
				19-Oct-23	250180	000	000200	102130-00	000200		0	0					NO		FEED MODE

Figure A-2 – A screenshot of Sjogren’s Microsoft Excel worksheet that displays the incomplete jobs for the Okuma Multus, using data from Global Shop.

A-3 – Matsuura H-Plus 300 Machine Table

STATUS	DATE_DUE	JOB	SUFFIX	SEQ	ROUTER	RSEQ	R	QTY	HRS REM	PERATT	SAW	MATL	TOMBSTONE	FACE	STOP	PROGRAM NAME	
proven	45250	250495	000	000100	28422-03	000100		0	0.25					# 5	A	N/A	22842203-1.TXT
proven	45250	250495	000	000110	28422-03	000100		2	1	MC				# 5	A	N/A	22842203-1.TXT
proven	45252	250530	000	000100	28422-14	000100		0	0.25					# 5	B	N/A	22842214-1.TXT
proven	45252	250530	000	000110	28422-14	000100		1	0.5	KURT6				# 5	B	N/A	22842214-1.TXT
proven	45252	250530	000	000200	28422-14	000200		0	0.25					# 5	B	N/A	22842214-1.TXT
proven	45252	250531	000	000100	28422-16	000100		0	0.25					# 5	A	N/A	22842216-1.TXT
proven	45252	250531	000	000110	28422-16	000100		1	0.5	KURT6				# 5	A	N/A	22842216-1.TXT
proven	45252	250531	000	000200	28422-16	000200		0	0.25					# 5	A	N/A	22842216-1.TXT
proven	45254	250680		000200	-94026-52	000200		0	0.5			Y		# 8	A-D	N/A	B-94026-52.TXT
proven	45254	250680		000250	-94026-52	000200		600	49.98			Y		# 8	A-D	N/A	B-94026-52.TXT
proven	45257	250767	000	000200	39043-00	000200		0	0.25					# 2	B	N/A	33904300-1.TXT
proven	45257	250767	000	000210	39043-00	000200		12	3	HR400				# 2	B	N/A	33904300-1.TXT
proven	45257	250767	000	000300	39043-00	000300		0	0.25					# 2	B	N/A	33904300-1.TXT
proven	45257	250768	000	000200	48319-01	000200		0	0.25					# 1	B	# 1	44831901-1.TXT
proven	45257	250768	000	000210	48319-01	000200		6	3	HR400				# 1	B	# 1	44831901-1.TXT
proven	45257	250768	000	000300	48319-01	000300		0	0.25					# 1	B	# 1	44831901-1.TXT
proven	45257	250769	000	000200	48426-01	000200		0	0.25					# 1	B	# 1	44842601-1.TXT
proven	45257	250769	000	000210	48426-01	000200		6	1.9998	HR300				# 1	B	# 1	44842601-1.TXT
proven	45257	250769	000	000300	48426-01	000300		0	0.25					# 1	B	# 1	44842601-1.TXT
PROVEN	45264	250563	000	000100	-2015200-52	000200		0	0.25			Y		# 8	A-D	N/A	B-2015200-52-1.TXT
PROVEN	45265	250566	000	000100	-2015200-62	000100		0	0.25			Y		# 8	A-D	N/A	B-2015200-62-1.TXT
PROVEN	45266	250565	000	000100	-2015200-59	000200		0	0.25			Y		# 8	A-D	N/A	B-2015200-59-1.TXT
PROVEN	45267	250564	000	000100	-2015200-55	000200		0	0.25			Y		# 8	A-D	N/A	B-2015200-55-1.TXT
PROVEN	45282	250782	000	000110	-2015200-55	000200		113	9.4129	BLCT4S		Y		# 8	A-D	N/A	B-2015200-55-1.TXT
PROVEN	45287	250813	000	000100	-2015200-55	000200		0	0.75			Y		# 8	A-D	N/A	B-2015200-55-1.TXT
PROVEN	45287	250813	000	000110	-2015200-55	000200		200	16.66	BLCT4S		Y		# 8	A-D	N/A	B-2015200-55-1.TXT
	45233	248118	000	000200		000000	Y	3	16.47			Y					
	45252	250562	000	000100	-2015200-39	000100		0	0.25			Y					
	45274	250784	000	000200	-94026-52-H	000200		0	0.5			Y					
	45274	250784	000	000210	-94026-52-H	000200		300	24.99			Y					

Figure A-3 – A screenshot of Sjogren’s Microsoft Excel worksheet that displays the incomplete jobs for the Matsuura H-Plus 300, using data from Global Shop.

Appendix B - Matsuura H-Plus 300 Photographs

B-1 – Matsuura H-Plus 300 Stop Numbers



Figure B-1 – Stop numbers 1 through 23 on the Matsuura H-Plus 300's Tombstone #3 Face C.

Appendix C – Deliverable 1 Initial Queries

C-1 – Layout of Initial Queries

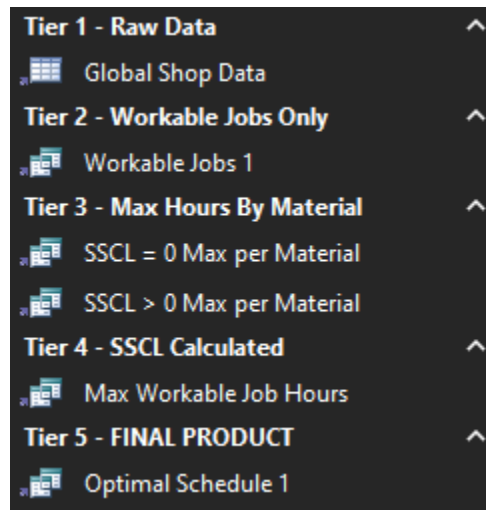


Figure C-1 – A screenshot of Microsoft Access’ navigation panel, which shows queries placed into custom groups to imitate the visual schema used in Figure 4.1.

C-2- Global Shop Data Table (Tier 1)

ID	PROVEN PRGM	MATERIAL	STOCK LENGTH OUT	DATE_DUE	JOB	SUFFIX	SEQ	ROUTER	RSEQ	R	QTY	HRS REM	SUB-SPINDLE USED	SUB SPINDLE COLLET	BAR FEED SETTING
1 Y	A		3	01-Nov-23	250142		000 000200	206524-00	000300	Y	0	0	NO		FEED MODE
2 Y	B		3	01-Nov-23	250142		000 000210	206524-00	000300	Y	1	4.5	NO		FEED MODE
3 Y	C		2.5	12-Oct-23	250185		000 000200	106930-00	000300	Y	0	0	YES	0.5	SUB SPINDLE MODE
4 Y	F		2.5	12-Oct-23	250185		000 000210	106930-00	000300	Y	5	36	YES	0.5	SUB SPINDLE MODE
5 Y	E		2.5	12-Oct-23	250183		000 000200	106928-00	000300	Y	0	0	YES	0.5	SUB SPINDLE MODE
6 Y	F		2.5	12-Oct-23	250183		000 000210	106928-00	000300	Y	4	26.4	YES	0.5	SUB SPINDLE MODE
7 Y	A		2.5	16-Oct-23	250186		000 000210	106931-00	000300	Y	4	16.008	YES	1.125	SUB SPINDLE MODE
8 Y	B		2.5	16-Oct-23	250186		000 000200	106931-00	000300	Y	0	0	YES	1.125	SUB SPINDLE MODE
9 Y	C		3	09-Oct-23	250075		000 000210	119836-02	000200	Y	8	60	NO		FEED MODE
10 Y	D		3	09-Oct-23	250076		000 000200	119836-03	000200	Y	0	0	NO		FEED MODE
11 Y	E		3	09-Oct-23	250076		000 000210	119836-03	000200	Y	8	60	NO		FEED MODE
12 Y	F		3	09-Oct-23	250075		000 000200	119836-02	000200	Y	0	0	NO		FEED MODE
13 Y	A		3	09-Oct-23	250074		000 000200	119836-01	000200	Y	0	0	NO		FEED MODE
14 Y	B		3	09-Oct-23	250074		000 000210	119836-01	000200	Y	8	60	NO		FEED MODE
15 Y	C		3	12-Oct-23	250184		000 000210	106929-00	000300	Y	3	23.994	YES	0.5	SUB SPINDLE MODE
16 Y	D		3	12-Oct-23	250130		000 000210	119821-00	000200	Y	4	40.8	YES	1	SUB SPINDLE MODE
17 Y	E		3	12-Oct-23	250130		000 000200	119821-00	000200	Y	0	0	YES	1	SUB SPINDLE MODE
18 Y	F		3	12-Oct-23	250184		000 000200	106929-00	000300	Y	0	0	YES	0.5	SUB SPINDLE MODE
19 Y	A		3	13-Oct-23	250178		000 000200	102129-01	000400	Y	0	0	YES	0.75	SUB SPINDLE MODE
20 Y	B		3	13-Oct-23	250178		000 000210	102129-01	000400	Y	9	54	YES	0.75	SUB SPINDLE MODE
21 Y	C		3	13-Oct-23	250036		000 000210	227583-01	000400	Y	3	23.994	NO		FEED MODE
22 Y	D		3	13-Oct-23	250036		000 000200	227583-01	000400	Y	0	0	NO		FEED MODE
23 Y	E		3	13-Oct-23	250035		000 000210	227582-01	000400	Y	3	23.994	NO		FEED MODE
24 Y	F		3	13-Oct-23	250035		000 000200	227582-01	000400	Y	0	0	NO		FEED MODE
25 Y	A		3.75	19-Oct-23	250179		000 000200	102129-02	000400	Y	0	0	YES	0.75	SUB SPINDLE MODE
26 Y	B		3.75	19-Oct-23	250179		000 000210	102129-02	000400	Y	3	14.994	YES	0.75	SUB SPINDLE MODE
27 Y	C		4	13-Oct-23	250037		000 000200	228219-00	000200	Y	0	0	YES	0.5	SUB SPINDLE MODE
28 Y	D		4	13-Oct-23	250037		000 000210	228219-00	000200	Y	6	43.2	YES	0.5	SUB SPINDLE MODE
29 Y	E		1.5	16-Oct-23	250195		000 000310	206929-00	000500	Y	4	19.992	YES	0.75	SUB SPINDLE MODE
30 Y	F		1.5	16-Oct-23	250195		000 000200	206929-00	000400	Y	0	0	YES	0.75	SUB SPINDLE MODE
31 Y	A		1.5	16-Oct-23	250195		000 000300	206929-00	000500	Y	0	0	YES	0.75	SUB SPINDLE MODE

Figure C-2 – A screenshot of the Global Shop Data table, which uses both real and made-up data to test the robustness of potential query solutions.

C-3 – Workable Jobs 1 Query (Tier 2)

PROVEN PRGM	MATERIAL	STOCK LENGTH OUT	DATE_DUE	JOB	SUFFIX	SEQ	ROUTER	RSEQ	R	QTY	HRS REM	SUB-SPINDLE USED	SUB SPINDLE COLLET	BAR FEED SETTING
N	B	3	01-Nov-23	250142	000	000210	206524-00	000300	Y	1	4.5	NO		FEED MODE
Y	F	2.5	12-Oct-23	250185	000	000210	106930-00	000300	Y	5	36	YES		0.5 SUB SPINDLE MODE
Y	F	2.5	12-Oct-23	250183	000	000210	106928-00	000300	Y	4	26.4	YES		0.5 SUB SPINDLE MODE
Y	A	2.5	16-Oct-23	250186	000	000210	106931-00	000300	Y	4	16.008	YES		1.125 SUB SPINDLE MODE
Y	C	3	09-Oct-23	250075	000	000210	119836-02	000200	Y	8	60	NO		FEED MODE
Y	E	3	09-Oct-23	250076	000	000210	119836-03	000200	Y	8	60	NO		FEED MODE
Y	B	3	09-Oct-23	250074	000	000210	119836-01	000200	Y	8	60	NO		FEED MODE
Y	C	3	12-Oct-23	250184	000	000210	106929-00	000300	Y	3	23.994	YES		0.5 SUB SPINDLE MODE
Y	D	3	12-Oct-23	250130	000	000210	119821-00	000200	Y	4	40.8	YES		1 SUB SPINDLE MODE
Y	B	3	13-Oct-23	250178	000	000210	102129-01	000400	Y	9	54	YES		0.75 SUB SPINDLE MODE
Y	C	3	13-Oct-23	250036	000	000210	227583-01	000400	Y	3	23.994	NO		FEED MODE
Y	E	3	13-Oct-23	250035	000	000210	227582-01	000400	Y	3	23.994	NO		FEED MODE
Y	B	3.75	19-Oct-23	250179	000	000210	102129-02	000400	Y	3	14.994	YES		0.75 SUB SPINDLE MODE
Y	D	4	13-Oct-23	250037	000	000210	228219-00	000200	Y	6	43.2	YES		0.5 SUB SPINDLE MODE
Y	E	1.5	16-Oct-23	250195	000	000310	206929-00	000500	Y	4	19.992	YES		0.75 SUB SPINDLE MODE
Y	B	1.5	16-Oct-23	250195	000	000210	206929-00	000400	Y	4	48	YES		0.75 SUB SPINDLE MODE
Y	E	1.5	18-Oct-23	250189	000	000210	106935-00	000300	Y	10	70.02	NO		FEED MODE
Y	F	1.5	18-Oct-23	250196	000	000250	207016-00	000300	Y	4	100.8	YES		0.625 SUB SPINDLE MODE
Y	B	1.5	19-Oct-23	250180	000	000210	102130-00	000200	Y	12	43.2	NO		FEED MODE
Y	D	1.5	20-Oct-23	250181	000	000210	106914-00	000200	Y	12	14.4	NO		FEED MODE
Y	F	2.5	17-Oct-23	250182	000	000210	106915-00	000300	Y	4	24	YES		1.25 SUB SPINDLE MODE
Y	A	2.25	05-Oct-23	250122	000	000110	338851-07	000200	Y	1	3.6	NO		FEED MODE
Y	C	2.25	09-Oct-23	250120	000	000110	338336-03	000100	Y	2	7.2	NO		FEED MODE
Y	E	1.375	03-Nov-23	249910	000	000210	106643-00	000200	Y	132	275.616	NO		FEED MODE
Y	F	2.5	13-Oct-23	249961	000	000210	106626-99	000200	Y	200	1140	NO		FEED MODE

Figure C-3 – A screenshot of the Workable Jobs 1 query, which filters out any data from the Global Shop Data table that contains a “PROVEN PRGM” value of “N” or a “QTY” value of 0.

C-4 – Max Hours by Material Queries (Tier 3)

C-4.1 – SSCL = 0 Max per Material Query

MATERIAL	SSC	HRSREM
A		3.6
B		107.7
C		91.194
D		14.4
E		429.63
F		1140

Figure C-4 – A screenshot of the SSCL = 0 Max per Material query, which displays each material’s total hours remaining for all jobs that do not have a sub-spindle collet value.

C-4.2 – SSCL > 0 Max per Material Query

MATERIAL	SSC	HRSREM
A	1.125	16.008
B	0.75	116.994
C	0.5	23.994
D	0.5	43.2
E	0.75	19.992
F	0.625	100.8

Figure C-5 – A screenshot of the SSCL > 0 Max per Material query, which displays each material’s sub-spindle collet value that has the highest total hours and the total hours associated with that sub-spindle collet value.

C-5 – SSCL Calculated Query (Tier 4)

Material ▾	Total Hours ▾
F	1240.8
E	449.622
B	224.694
C	115.188
D	57.6
A	19.608

Figure C-6 – A screenshot of the Max Workable Job Hours query, which sums the results from both Max Hours by Material queries to display the total possible overnight hours for each material in order from highest total hours to lowest total hours.

C-6 – FINAL PRODUCT Query (Tier 5)

JOB ▾	MATERIAL ▾	STOCK LENGTH OUT ▾	HRS REM ▾	SUB-SPINDLE USED ▾	SUB SPINDLE COLLET ▾
249961	F	2.5	1140	NO	
250196	F	1.5	100.8	YES	0.625
*					0

Figure C-7 – A screenshot of the Optimal Schedule 1 query, which displays all jobs associated with the material with the highest hours, as determined in the Max Workable Job Hours query, and the information associated with each job.

Appendix D - Deliverable 1 Polished Queries

D-1 – Polished Queries Simplified Layout

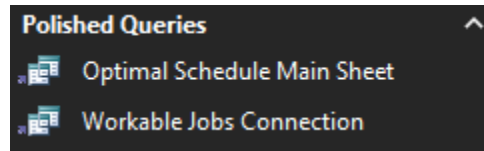


Figure D-1 – A screenshot of Microsoft Access’ navigation panel, which shows the two final queries placed into a custom group.

D-2 – Connection Query

PROVEN PRGM	MATERIAL	STOCK LENGTH OUT	DATE_DUE	JOB	SUFFIX	SEQ	ROUTER	RSEQ	R	QTY	HRS REM	SUB-SPINDLE USED	SUB SPINDLE COLLET
Y	A2R1.250	3	01-Nov-23	250142	000	000210	206524-00	000300	Y	1	4.5	NO	
Y	C12L14R1.625	2.5	12-Oct-23	250185	000	000210	106930-00	000300	Y	5	36	YES	0.5
Y	C12L14R1.625	2.5	12-Oct-23	250183	000	000210	106928-00	000300	Y	4	26.4	YES	0.5
Y	C12L14R1.625	2.5	16-Oct-23	250186	000	000210	106931-00	000300	Y	4	16.008	YES	1.125
Y	C12L14R1.625	3	09-Oct-23	250075	000	000210	119836-02	000200	Y	8	60	NO	
Y	C12L14R1.625	3	09-Oct-23	250076	000	000210	119836-03	000200	Y	8	60	NO	
Y	C12L14R1.625	3	09-Oct-23	250074	000	000210	119836-01	000200	Y	8	60	NO	
Y	C12L14R1.625	3	12-Oct-23	250184	000	000210	106929-00	000300	Y	3	23.994	YES	0.5
Y	C12L14R1.625	3	12-Oct-23	250130	000	000210	119821-00	000200	Y	4	40.8	YES	1
Y	C12L14R1.625	3	13-Oct-23	250178	000	000210	102129-01	000400	Y	9	54	YES	0.75
Y	C12L14R1.625	3	13-Oct-23	250036	000	000210	227583-01	000400	Y	3	23.994	NO	
Y	C12L14R1.625	3	13-Oct-23	250035	000	000210	227582-01	000400	Y	3	23.994	NO	
Y	C12L14R1.625	3.75	19-Oct-23	250179	000	000210	102129-02	000400	Y	3	14.994	YES	0.75
Y	C12L14R1.625	4	13-Oct-23	250037	000	000210	228219-00	000200	Y	6	43.2	YES	0.5
Y	C12L14R2.500	1.5	16-Oct-23	250195	000	000310	206929-00	000500	Y	4	19.992	YES	0.75
Y	C12L14R2.500	1.5	16-Oct-23	250195	000	000210	206929-00	000400	Y	4	48	YES	0.75
Y	C12L14R2.500	1.5	18-Oct-23	250189	000	000210	106935-00	000300	Y	10	70.02	NO	
Y	C12L14R2.500	1.5	18-Oct-23	250196	000	000250	207016-00	000300	Y	4	100.8	YES	0.625
Y	C12L14R2.500	1.5	19-Oct-23	250180	000	000210	102130-00	000200	Y	12	43.2	NO	
Y	C12L14R2.500	1.5	20-Oct-23	250181	000	000210	106914-00	000200	Y	12	14.4	NO	
Y	C12L14R2.500	2.5	17-Oct-23	250182	000	000210	106915-00	000300	Y	4	24	YES	1.25
Y	C4140R1.250HT	2.25	05-Oct-23	250122	000	000110	338851-07	000200	Y	1	3.6	NO	
Y	C4140R1.250HT	2.25	09-Oct-23	250120	000	000110	338336-03	000100	Y	2	7.2	NO	
Y	O1R0.750	1.375	03-Nov-23	249910	000	000210	106643-00	000200	Y	132	275.616	NO	

Figure D-2 – A screenshot of the Workable Jobs Connection query, which filters out any data from Sjogren’s Global Shop Data table that contains a “PROVEN PRGM” value of “N” or a “QTY” value of 0.

D-3 – Optimization Query

PROVEN PRGM	MATERIAL	STOCK LENGTH OUT	HRS REM	SUB-SPINDLE USED	SUB SPINDLE COLLET
Y	O1R0.750	2.5	1140	NO	
Y	O1R0.750	1.375	275.616	NO	
*					0

Figure D-3 – A screenshot of the Optimal Schedule Main Sheet query, which has the functionality of all 5 queries created in Appendix C and relies on the Workable Jobs Connection query for data.

Appendix E - Deliverable 2 Microsoft Excel

E-1 – VBA Macro Script

```
Sub FINAL_OPTIMIZATION()  
,  
,  
' FINAL_OPTIMIZATION Macro  
,  
,  
,  
  
Sheets("HR400 Calculator").Select  
  
ActiveSheet.Unprotect  
  
Sheets("HR400 Jobs").Select  
  
ActiveSheet.Unprotect  
  
Sheets("HR125 Calculator").Select  
  
ActiveSheet.Unprotect  
  
Sheets("HR125 Jobs").Select  
  
ActiveSheet.Unprotect  
  
Sheets("HR600 Calculator").Select  
  
ActiveSheet.Unprotect  
  
Sheets("HR600 Jobs").Select  
  
ActiveSheet.Unprotect  
  
Sheets("HR200 Calculator").Select  
  
ActiveSheet.Unprotect
```

Sheets("HR200 Jobs").Select

ActiveSheet.Unprotect

Sheets("HR300 Calculator").Select

ActiveSheet.Unprotect

Sheets("HR300 Jobs").Select

ActiveSheet.Unprotect

ActiveWorkbook.RefreshAll

ThisWorkbook.Worksheets("HR400 Calculator").Activate

SolverReset

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverAdd CellRef:="\$B\$1:\$B\$97", Relation:=4, FormulaText:="integer"

SolverAdd CellRef:="\$D\$1:\$D\$97", Relation:=4, FormulaText:="integer"

SolverAdd CellRef:="\$F\$1:\$F\$97", Relation:=1, FormulaText:="\$H\$1:\$H\$97"

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverAdd CellRef:="\$Q\$2:\$Q\$3", Relation:=1, FormulaText:="\$S\$2:\$S\$3"

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverSolve UserFinish:=True

ThisWorkbook.Worksheets("HR125 Calculator").Activate

SolverReset

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverAdd CellRef:="\$B\$1:\$B\$97", Relation:=4, FormulaText:="integer"

SolverAdd CellRef:="\$D\$1:\$D\$97", Relation:=4, FormulaText:="integer"

SolverAdd CellRef:="\$F\$1:\$F\$97", Relation:=1, FormulaText:="\$H\$1:\$H\$97"

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverAdd CellRef:="\$Q\$2:\$Q\$3", Relation:=1, FormulaText:="\$S\$2:\$S\$3"

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverSolve UserFinish:=True

ThisWorkbook.Worksheets("HR600 Calculator").Activate

SolverReset

SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _

"\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"

SolverAdd CellRef:="\$B\$1:\$B\$97", Relation:=4, FormulaText:="integer"
 SolverAdd CellRef:="\$D\$1:\$D\$97", Relation:=4, FormulaText:="integer"
 SolverAdd CellRef:="\$F\$1:\$F\$97", Relation:=1, FormulaText:="\$H\$1:\$H\$97"
 SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _
 "\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"
 SolverAdd CellRef:="\$Q\$2:\$Q\$3", Relation:=1, FormulaText:="\$S\$2:\$S\$3"
 SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _
 "\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"
 SolverOk SetCell:="\$Q\$5", MaxMinVal:=1, ValueOf:=0, ByChange:= _
 "\$B\$1:\$B\$97,\$D\$1:\$D\$97", Engine:=2, EngineDesc:="Simplex LP"
 SolverSolve UserFinish:=True

ThisWorkbook.Worksheets("HR200 Calculator").Activate

SolverReset

SolverOk SetCell:="\$V\$6", MaxMinVal:=1, ValueOf:=0, ByChange:= _
 "\$B\$1:\$B\$66,\$D\$1:\$D\$66,\$F\$1:\$F\$66", Engine:=2, EngineDesc:="Simplex LP"
 SolverAdd CellRef:="\$B\$1:\$B\$66", Relation:=4, FormulaText:="integer"
 SolverAdd CellRef:="\$D\$1:\$D\$66", Relation:=4, FormulaText:="integer"
 SolverAdd CellRef:="\$F\$1:\$F\$66", Relation:=4, FormulaText:="integer"
 SolverAdd CellRef:="\$H\$1:\$H\$66", Relation:=1, FormulaText:="\$J\$1:\$J\$66"
 SolverAdd CellRef:="\$V\$2:\$V\$4", Relation:=1, FormulaText:="\$X\$2:\$X\$4"
 SolverOk SetCell:="\$V\$6", MaxMinVal:=1, ValueOf:=0, ByChange:= _
 "\$B\$1:\$B\$66,\$D\$1:\$D\$66,\$F\$1:\$F\$66", Engine:=2, EngineDesc:="Simplex LP"

SolverOk SetCell:="\$V\$6", MaxMinVal:=1, ValueOf:=0, ByChange:= _
"\$B\$1:\$B\$66,\$D\$1:\$D\$66,\$F\$1:\$F\$66", Engine:=2, EngineDesc:"Simplex LP"
SolverSolve UserFinish:=True

ThisWorkbook.Worksheets("HR300 Calculator").Activate

SolverReset

SolverOk SetCell:="\$V\$6", MaxMinVal:=1, ValueOf:=0, ByChange:= _
"\$B\$1:\$B\$66,\$D\$1:\$D\$66,\$F\$1:\$F\$66", Engine:=2, EngineDesc:"Simplex LP"
SolverAdd CellRef:="\$B\$1:\$B\$66", Relation:=4, FormulaText:"integer"
SolverAdd CellRef:="\$D\$1:\$D\$66", Relation:=4, FormulaText:"integer"
SolverAdd CellRef:="\$F\$1:\$F\$66", Relation:=4, FormulaText:"integer"
SolverAdd CellRef:="\$H\$1:\$H\$66", Relation:=1, FormulaText:"\$J\$1:\$J\$66"
SolverAdd CellRef:="\$V\$2:\$V\$4", Relation:=1, FormulaText:"\$X\$2:\$X\$4"
SolverOk SetCell:="\$V\$6", MaxMinVal:=1, ValueOf:=0, ByChange:= _
"\$B\$1:\$B\$66,\$D\$1:\$D\$66,\$F\$1:\$F\$66", Engine:=2, EngineDesc:"Simplex LP"
SolverOk SetCell:="\$V\$6", MaxMinVal:=1, ValueOf:=0, ByChange:= _
"\$B\$1:\$B\$66,\$D\$1:\$D\$66,\$F\$1:\$F\$66", Engine:=2, EngineDesc:"Simplex LP"
SolverSolve UserFinish:=True

Sheets("HR300 Jobs").Select

ActiveSheet.Protect DrawingObjects:=True, Contents:=True, Scenarios:=True

Sheets("HR300 Calculator").Select

ActiveSheet.Protect DrawingObjects:=False, Contents:=True, Scenarios:= _

False

Sheets("HR200 Jobs").Select

ActiveSheet.Protect DrawingObjects:=False, Contents:=True, Scenarios:= _

False

Sheets("HR200 Calculator").Select

ActiveSheet.Protect DrawingObjects:=False, Contents:=True, Scenarios:= _

False

Sheets("HR600 Jobs").Select

ActiveSheet.Protect DrawingObjects:=True, Contents:=True, Scenarios:=True

Sheets("HR600 Calculator").Select

ActiveSheet.Protect DrawingObjects:=False, Contents:=True, Scenarios:= _

False

Sheets("HR125 Jobs").Select

ActiveSheet.Protect DrawingObjects:=True, Contents:=True, Scenarios:=True

Sheets("HR125 Calculator").Select

ActiveSheet.Protect DrawingObjects:=False, Contents:=True, Scenarios:= _

False

Sheets("HR400 Jobs").Select

ActiveSheet.Protect DrawingObjects:=True, Contents:=True, Scenarios:=True

Sheets("HR400 Calculator").Select

ActiveSheet.Protect DrawingObjects:=True, Contents:=True, Scenarios:=True

Sheets("Optimal Jobs Overview").Select

End Sub