University of Southern Indiana
Pott College of Science, Engineering, and Education
Engineering Department
8600 University Boulevard
Evansville, Indiana 47712

Data Driven Decision Making through Mathematical Modeling

Dennis Lopez Martinez
MFET 471 – Senior Project
Spring 2024

ACKNOWLEDGEMENTS

I would like to acknowledge the following people for their help throughout the entire project. Their help and support were instrumental in making this project possible.

Faculty

Dr. Ely

Past Students

Maggie Bolin (Toyota)

Dylan Eagan (Gibbs)

ABSTRACT

The COVID-19 pandemic has had a profound impact on supply chains across multiple industries, including the automotive sector. It has exposed notable challenges, such as navigating through unexpected delays, sourcing necessary supplies, and facing shortages of both raw materials and workforce. These challenges have had a direct and disruptive impact on production lines, creating obstacles that hinder the smooth flow of operations and pose significant challenges to maintaining productivity. Unfortunately, professionals have often been left to rely on intuition rather than data-driven analysis when making crucial decisions in these situations.

To address these issues a customizable Excel based program has been created for optimizing decision making. The mathematical model was developed using Excel to harness data-driven analysis offering valuable insights and recommendations. The model will evaluate and weigh various alternatives, such as bringing in alternative equipment, sourcing parts from local suppliers, or allocating additional personnel. By utilizing this model, companies will be empowered to make informed decisions based on objective analysis rather than relying solely on gut instincts.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1.0 Introduction

In today’s rapid manufacturing industry, when production lines halt, it's more than just a temporary stop. It signifies a loss in money, production, time, and numerous other resources. Imagine a scenario where every minute of downtime costs the company upwards of $250,000. In such circumstances it is imperative to find quick solutions. Usually, the ones solving such issues consists of operators, management, engineers, and other people from various departments. They each bring unique perspectives, educational backgrounds, and skill sets. Despite the company saying they make data driven decisions the reality is a chaotic debate on the production floor where the loudest voice prevails. The pressure to find a solution quickly is immense because every minute of downtime translates to significant financial losses. While it's a high-pressure environment it is still essential to rely on data versus basing decisions on gut intuition. Decision-making shouldn't be based on who speaks the loudest; instead, it should be based on data-driven objective.

2.0 Background

Approximately four years after the start of the pandemic, the lingering impact of COVID-19 is still evident across various industries, fundamentally changing the way they operate. Traditional best practices were no longer effective as the pandemic disrupted operations, altered consumer demand, and revealed vulnerabilities in global supply chains. It led to unforeseen delays, sourcing challenges and workforce shortages. Companies realized the need to enhance supply chain visibility, diversify supplier networks, develop robust contingency plans, improve flexibility, and strengthen communication channels to address future disruptions effectively.

Ernst and Young found that the pandemic sped up problems that were already there, making companies focus more on making their supply chains stronger and greener. (Ernst and Young, 2022). This means investing in new tech like AI and automation. Organizations turned to digital tools and technologies such as automation and advanced analytics, to enhance efficiency, ensure business continuity, and manage risks both in the long and short term. Remote collaboration and virtual training also became essential as people adapted to remote work arrangements. Additionally, labor shortages and transportation disruptions prompted organizations to seek alternative solutions and implement safety measures to maintain the flow of goods. Concurrently, there is an ongoing shortage of skilled workers, but many companies are proactively seeking ways to attract the new generation to this field. They are accomplishing this through innovative recruitment strategies, improved workplace conditions, and investment in technology and training programs. Manufacturers aim to appeal to the younger generation and motivate them to pursue careers in manufacturing.

The pandemic has pushed for innovation and transformation, prompting industries to rethink and adapt their operations to the new normal. Digital tools and technologies have played a crucial role in enabling remote work, enhancing visibility, and improving decision-making. Organizations have also recognized the importance of resilience, risk management, and agility in the face of unexpected disruptions. As a result, they are increasingly adopting strategies that prioritize adaptability, flexibility, and collaboration across the entire supply chain to mitigate risks and ensure operational continuity.

2.2 Objective and Motivation

The primary motivation for this project was driven by the participation in a research project on "Changes in lean six sigma in organizations pre- and post-COVID," conducted alongside Dr. Ely and fellow students. This research experience sparked a desire to explore the topic further and explore potential solutions to address the disruptions caused by the pandemic. Through the research, it became clear that numerous companies were predominantly relying on intuition-based decision-making rather than data-driven methodologies. Several challenges emerged regarding the maintenance of efficient supply chains, including unexpected delays, shortages of raw materials and workforce, and the sourcing of necessary supplies.

To tackle this issue, the project centered on gathering solid evidence and conducting meticulous numerical analysis to showcase the advantages of data-driven decision-making. The primary objective is to provide companies with tangible insights and compelling numbers. This would serve as a persuasive tool to encourage them to opt for data-driven approaches that aligned with long-term success and minimized the potential risks associated with relying solely on intuition.

2.3 Review of existing solutions and/or review of relevant literature

In the decision-making process, careful consideration will be given to various key performance indicators and factors. The primary objective is to thoroughly analyze each alternative, weighing the pros and cons associated with choosing that particular option. If the decision is made to replace equipment and make investments, Toyota, whose data will be used to validate our tool, aims to achieve a return on investment (ROI) within a two-year timeframe for all investments. Additionally, Toyota assess whether takt time can be maintained in the event of robot backups and whether any quality concerns may arise. Lead times and safety considerations are also vital components of the decision-making criteria. Each alternative will be evaluated and weighted differently, as the model is designed to handle diverse scenarios, and these decision constraints can be modified for other companies to ensure each user has the model configured to their company's policies and goals.

During the research It was discovered that many companies are adopting different approaches in response to post COVID. One interesting trend, as highlighted in the article “Automation or Human Labor? Here’s What to Consider" by Arnold Machine, is the growing reliance on automation. This shift towards automation brings several advantages, including improved efficiency, cost reduction, increased productivity, and enhanced safety. However, it also presents challenges that companies need to address. These challenges include workforce shortages, the cost of implementation, potential errors or inefficiencies, and technological vulnerabilities.

One-way companies are embracing automation is by using technologies like robotic process automation (RPA) and artificial intelligence (AI) to automate routine tasks (Sisua Digital, 2022). This helps businesses simplify processes, minimize errors, and free up human resources for more strategic projects. By freeing up time and resources, automation can lead to increased productivity, improved product quality, and reduced defects. Supply chain management is also being transformed through automation. Technologies like IoT, blockchain, and autonomous vehicles are optimizing inventory management, real-time shipment tracking, and logistics operations, resulting in improved visibility, faster delivery, and increased efficiency (Smith, 2018). However, companies must carefully consider the initial investment and ongoing costs associated with implementing automation, as well as potential disruptions caused by system failures or cyber threats.

Automation offers benefits, but it also presents challenges. According to Bibin Dominic's article "How to Build the next Generation of Manufacturers" companies can overcome these challenges by prioritizing training and upskilling their workforce. Dominic suggests that companies should ensure a future supply of skilled workers and invest in training programs to equip employees with the necessary skills to work alongside automated systems. This approach will help employees adapt to changing job requirements and address potential shortages in automation-related fields (Dominic, 2023).

An article titled "5 Ways the COVID-19 Pandemic Has Changed the Supply Chain" explores how companies are adapting to new supply chain models and closely monitoring their balanced scorecards. Buyer-supplier relationships are evolving, with some manufacturers embracing forward contracting and acquiring warehouses. Additionally, manufacturers are reassessing their just-in-time (JIT) practices. Despite the disruptive impact of COVID-19 on the automotive supply chain, it has also created opportunities to establish a stronger presence in the United States by leveraging automation and other emerging technologies. Adopting a flexible mindset is crucial in addressing the supply chain challenges arising from the pandemic (How The COVID-19 Pandemic Has Changed Supply Chain Practices, 2022).

3.0 Conceptual Design

The absence of decision-making tools compelled professionals to rely on their instincts rather than data-driven analysis, leading to less effective decisions. To tackle this problem, a mathematical tool has been created and tailored to meet the needs of the stakeholders. The tool offers mathematical analysis and evaluates different alternatives, that can aid professionals in the automotive and various other industries in making optimized management decisions. To ensure that the end user comprehends the proper use of the tool, guidance notes will be generated and integrated into the first tab of the tool. The development of this proposed mathematical decision-making tool will involve the following steps:

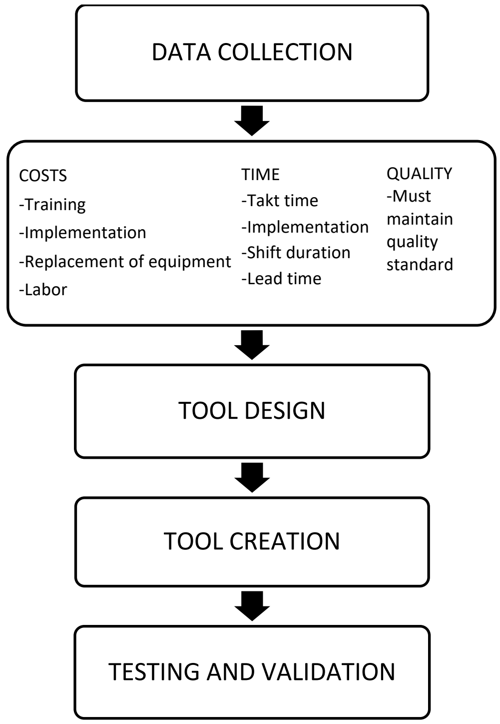


Figure 1 Development of tool

The diagram shows the process of developing a mathematical tool. It starts with gathering information for decision-making. Costs, like training, implementation, equipment replacement, and labor, are important factors to consider. Time-related aspects, such as takt time, implementation time, shift duration, lead times, and downtime, also play a role. Quality is crucial to ensure that decision-making processes meet high standards and yield the desired outcomes. Tool design focuses on creating user-friendly interfaces. Tool creation turns the design into a working software tool. Testing and validation are conducted to ensure the accuracy and reliability of the tool, making it accessible to all individuals. The first tab of the tool will serve as a training document, explaining all of its features and functionality.

3.1 Requirement Specifications

This section presents the requirement specifications for the Mathematical model, which were gathered from stakeholders.

Customization and Flexibility

- Options for customization and adjusting parameters to cater to different scenarios and specific needs.

- Ability to incorporate new data sources or modify existing ones to adapt to changing requirements.
- Customizable reporting and visualization capabilities to present information in a format that suits stakeholders' preferences.
- Scalability to accommodate future growth and expansion, allowing for increased data volume and complexity.

Handle Various Scenarios and Inputs

- Scenario Templates: Provide pre-configured scenario templates making it easier for users to get started without manually configuring all parameters.
- Evaluate various alternatives, including alternative suppliers, custom jobs, equipment replacement, automated to manual processes.

Ease of Use

- Ensuring that it can be utilized by anyone without extensive technical expertise.

3.2 End User Evaluation Criteria

The end user evaluation criteria prioritize economic focus, aiming to identify the most cost-effective choice. However, the most critical aspect is quality, as the tool must consistently deliver the correct output. While cost-effectiveness is crucial, it cannot overshadow the importance of reliability and precision in achieving the desired results. The evaluation process must strike a balance between economic considerations and the assurance of high-quality performance to meet the end user's needs effectively.

3.3 Evaluation of alternatives

The evaluation of the three alternatives for the mathematical model, considering ease of use as a key constraint, suggests that Excel is the most suitable choice. Here's a breakdown of the evaluation:

	Ease of Use	**Accessibility**	**Customization**	**Cost**
Excel	Easy to use	Widely available	Limited customization	May have a fee
Minitab	User-friendly	Less common	Limited customization	Licensing fee
MATLAB	Not user-friendly	Less common	Extensive customization	Licensing fee

Table 1 Matrix of alternatives

Excel:

- Ease of Use: Excel is easy to use, familiar to many, and offers various math and data analysis tools.
- Accessibility: Excel is widely available, standard in many organizations, and supports easy file sharing.
- Cost: Excel may come with a fee, but it's commonly found in standard software packages or offered through subscriptions.

Minitab:

- Ease of Use: Minitab is user-friendly for statistics but less known to the general audience. Training may be needed for its advanced features.
- Accessibility: Minitab is not as common as Excel, which might create challenges in terms of sharing and collaboration. Licenses may also be required, which could be costly.
- Customization: Minitab's customization options are more focused on statistical analysis and quality improvement, and it might not be as flexible for custom mathematical modeling.
- Cost: Typically involves a licensing fee, which can be relatively expensive.

MATLAB

- Ease of Use: MATLAB is strong for math and engineering but not very user-friendly for non-experts due to its learning curve.
- Accessibility: Less common outside technical fields and can be costly. Collaboration and sharing may be limited due to its specialization.
- Customization: MATLAB allows extensive customization for modeling but demands technical expertise.
- Cost: Typically involves a licensing fee, which can be relatively expensive.

In summary, Excel seems best suited for this project due to its ease of use, accessibility, familiarity, and cost. However, for a project that requires advanced modeling or analysis, Minitab or MATLAB may be options, but they need more training and resources for user-friendliness.

3.4 Development of Optimization Tool

The goal of this tool is to develop a customizable Excel-based program for optimizing decision-making.

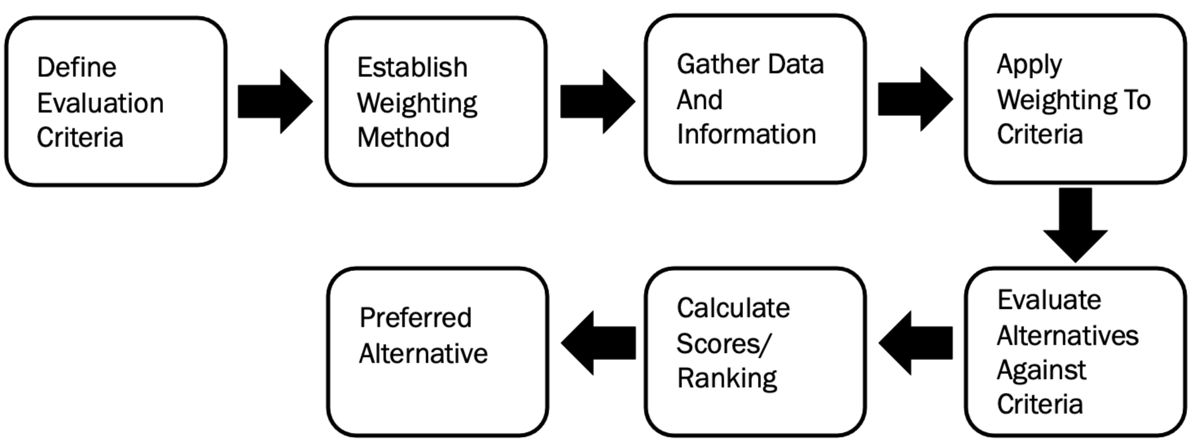


Figure 2 Process Flow

In analyzing the diagram, the process begins by identifying the key factors essential for evaluating alternatives. Once these factors are identified, the next step involves determining the relative importance of each factor. Following this, relevant data is collected for both the alternatives and criteria outlined. With data in hand, weights are assigned to each criterion based on their respective importance in the decision-making process. Subsequently, each alternative is assessed against the established criteria to gauge its performance. These individual evaluations are then combined to calculate overall scores or rankings for each alternative. Finally, the alternative with the highest score/ ranking is selected as the preferred choice.

4.0 Description of Program

The first tab serves as the input page as shown on **Error! Reference source not found.** where various fields are filled out. Not all fields need to be completed as they depend on the scenario being considered. This sheet analyzes both downtime costs and improvement costs. The second tab, labeled "Results," provides an overview and indicates which cost is lower as shown in Figure 4. It also presents the preferred alternative based on both short-term and long-term perspectives. Additionally, there is a chart that visually represents the data for better understanding. The third sheet, denoted as "Math," Figure 5 serves as the repository for all equations, discreetly hidden to facilitate comprehensive calculations.

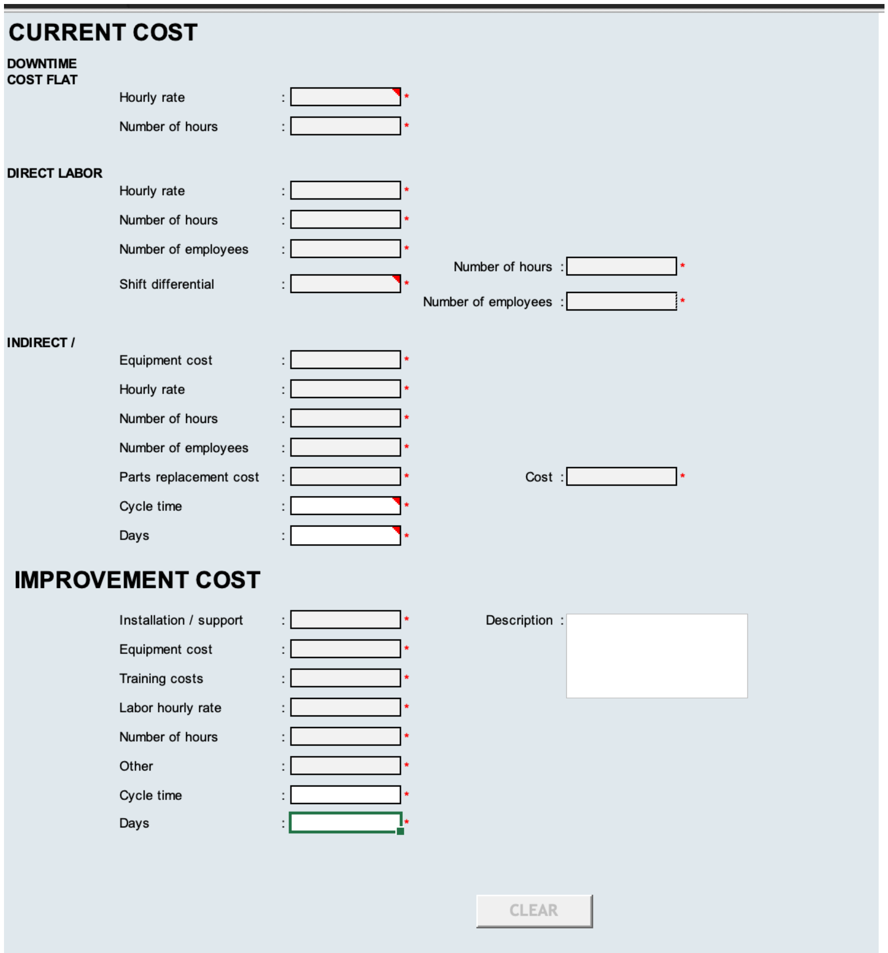


Figure 3 Data Entry Sheet

OVERVIEW			
COST OF DOWNTIME	COST OF IMPROVEMENT	HOURS TO COST EQUALITY (Year)	PRODUCTIVITY GAIN
$0.00	$0.00	-	-
Both Costs are Equal			

Figure 4 Results Sheet

Known	
HOURLY RATE	$31.30
HOURS/SHIFT	8
OVERTIME	1.5x

Productivity Gain

Current	New
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
Total	#DIV/0!

COST OF DOWNTIME	:	Downtime cost flat rate + Direct labor + Shift differential + Indirect cost + Parts replacement
COST OF IMPROVEMENT	:	Equipment Cost + Training Cost + (Labor Cost per Hour * Number of Hours) + Other Costs
HOURS TO COST EQUALITY	:	(Cost of improvement / hourly cost of employee)/ 365

Figure 5 Math Sheet

5.0 Case Study 1 (Toyota)

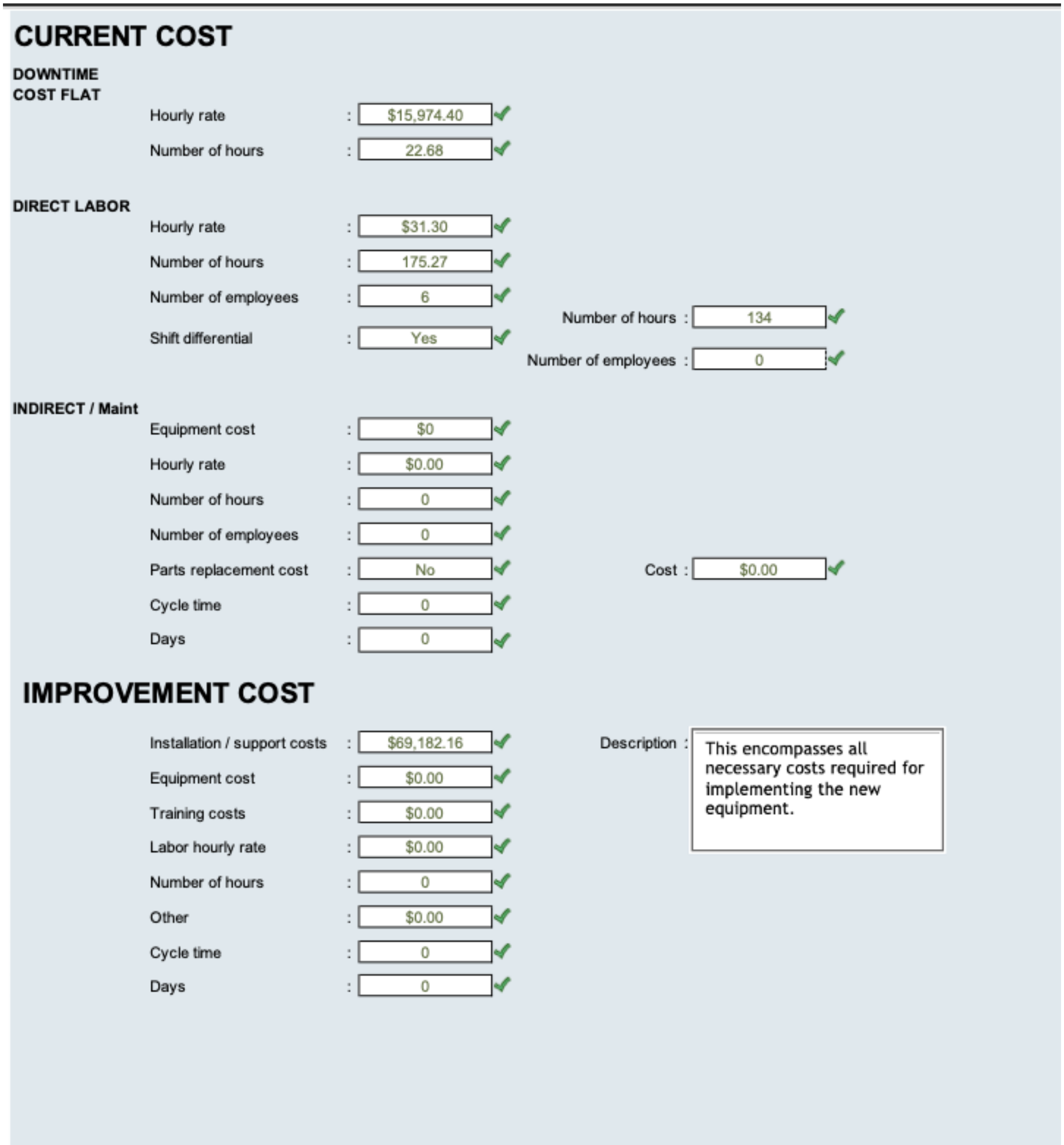
In May 2023, Toyota faced significant production and takt time disruptions when two robots broke down. The subsequent backup process caused delays, with one robot being repaired within a few days while the other required backup for a lengthy two-week period. Quality concerns arose during the backup process, and staffing was significantly affected due to manual intervention. The root cause was identified as inadequate troubleshooting by the maintenance team, resulting in unnecessary part replacements. Although ongoing issues with the robots persist, the company has resolved the manual backup process. However, obtaining a replacement took a significant amount of time due to backorder issues, prompting the company to implement short-term solutions.

In such scenarios, decision-making tools become crucial. Relying solely on intuition can be problematic, as it is subjective, prone to biases, and limited in perspective. Data-driven analysis offers objective insights, mitigates biases, and enables more informed choices. By considering multiple variables and potential impacts, data-driven analysis ensures rational and evidence-based decision-making. While intuition can complement data analysis, it should not be the sole determinant of decisions. Embracing a data-driven approach enhances objectivity and ensures decisions are aligned with long-term success.

To address the equipment issues, Toyota considered several options:

1. Fixing existing equipment: Although additional training was deemed necessary, progress in this area has been limited.
2. Purchasing and installing new equipment: However, the lead time for the chosen equipment is 12 to 14 months, and upgrades are currently unfeasible within the budget constraints.
3. Hiring the Original Equipment Manufacturer (OEM): Previous attempts to seek assistance from the OEM were unsuccessful due to inadequate support.

Toyota provided data to input into the Excel sheet to determine if it is cost effective to stay the way they have been operating or to just go ahead and replace the equipment. Figures 6 and 7 visually depict the appearance of the data entry interface after data insertion, along with the corresponding results. It should be noted that not every box will be tabulated; the outcome depends on the user's input and dictates the results.



CURRENT COST

DOWNTIME COST FLAT

Hourly rate	$15,974.40
Number of hours	22.68

DIRECT LABOR

Hourly rate	$31.30
Number of hours	175.27
Number of employees	6
Shift differential	Yes
Number of hours	134
Number of employees	0

INDIRECT / Maint

Equipment cost	$0
Hourly rate	$0.00
Number of hours	0
Number of employees	0
Parts replacement cost	No
Cost	$0.00
Cycle time	0
Days	0

IMPROVEMENT COST

Installation / support costs	$69,182.16
Equipment cost	$0.00
Training costs	$0.00
Labor hourly rate	$0.00
Number of hours	0
Other	$0.00
Cycle time	0
Days	0

Description : This encompasses all necessary costs required for implementing the new equipment.

Figure 6 Toyota's Data Entry Scenario

OVERVIEW			
COST OF DOWNTIME	COST OF IMPROVEMENT	HOURS TO COST EQUALITY (Years)	PRODUCTIVITY GAIN
$395,215.10	$69,182.16	0.03	#DIV/0!
Cost of Improvement is Lower			

Figure 7 Toyota's Results

Results

The results show the total down time cost for that projected period that they are down which is equal to $394,215.10 versus the total cost of improvement totaling to $69,182.16. This showcase that it is more cost-effective to invest in improvements rather that to continue to operate the way they have been.

6.0 Case Study 2 (Gibbs)

Currently Gibb's operation is manual. However, they are evaluating whether to continue to be manual or to switch their operation to an automated system. Intuitively, you recognize that an operation where you have to put someone at twenty-four hours a day, seven days a week, costs a lot of money. This program enables you to easily assess the cost of your improvements by inputting labor costs and calculating potential savings.

The data provided by Gibb's is as follows:

- Hourly rate: $22
- 24-hour shifts worked over 365 days
- Current cycle time: 72 seconds
- New cycle time: 70 seconds
- Improvement cost: $216,667

Results

Overall, the results indicate that the cost of implementation and the payback period span over 1.2 years. The reduction in cycle time by 2 seconds resulted in an additional 14,069 units produced per year. This underscores the tangible benefits of opting for automation over manual labor, confirming the superiority of robots in this scenario.

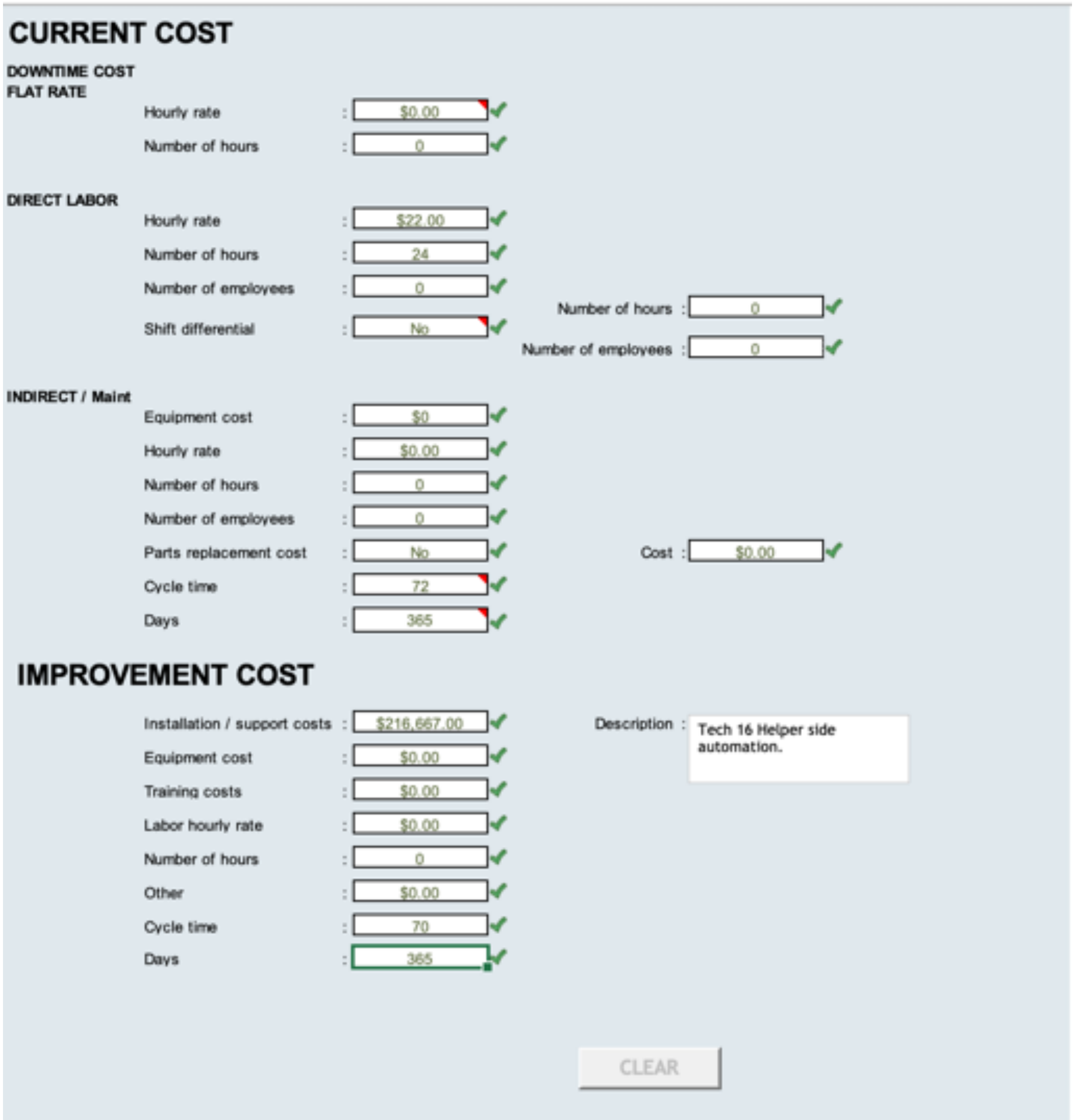


Figure 8 Gibbs Data Entry Scenario

OVERVIEW			
COST OF DOWNTIME	COST OF IMPROVEMENT	HOURS TO COST EQUALITY (Years)	PRODUCTIVITY GAIN
$0.00	$216,667.00	1.12	14069.29

Figure 9 Gibb's Results

7.0 Conclusion

This project is a response to the changing landscape brought about by the COVID-19 pandemic. It advocates for a shift towards data-driven decision-making. The efficacy of this tool lies not only in its ability to provide objective insights but also in its capacity to expedite decision-making. By delivering results within minutes, it has eliminated the need for engineers to manually compute complex equations or undertake lengthy projects to evaluate alternatives. This streamlined process has not only enhanced operational efficiency but has also enabled swift responses to emerging challenges and opportunities. As industries continue to evolve, embracing technological innovations and data-driven approaches becomes crucial for long-term success and operational continuity

References

Corwin, et al. "The Futures of Mobility after COVID-19: Scenarios for Transportation in a Post coronavirus World." Part of a Deloitte Series on the Future of Mobility. Deloitte, n.d. Web. 9 Apr. 2024. https://www2.deloitte.com/content/dam/insights/us/articles/6739_fom-covid/DI_FoM-COVID.pdf

Dominic, Bibin. "How to Build the Next Generation of Manufacturers." Cogneesol Blog, 31 Oct. 2023. Web. 9 Apr. 2024. https://www.cogneesol.com/blog/next-generation-of-manufacturers-what-would-it-look-like/

"How the COVID-19 Pandemic Has Changed Supply Chain Practices." World Economic Forum. n.d. Web. 9 Apr. 2024. https://www.weforum.org/agenda/2022/01/5-ways-the-covid-19-pandemic-has-changed-the-supply-chain/

Holzer, Harry J. “Understanding the Impact of Automation on Workers, Jobs, and Wages. *Brookings*, 19 Jan. 2022, www.brookings.edu/articles/understanding-the-impact-of-automation-on-workers-jobs-and-wages

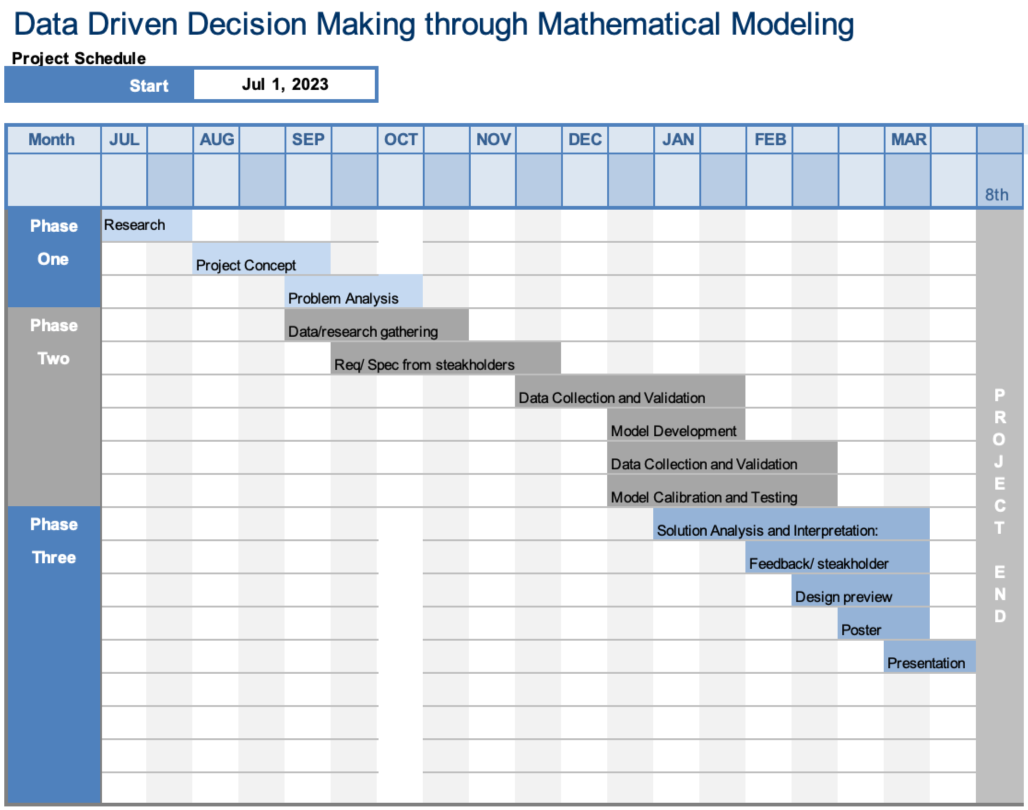
"Robotic Process Automation in the Post Covid-19 Era." Sisua Digital, 16 Nov. 2022. Web. 9 Apr. 2024. https://sisuadigital.com/blog/robotic-process-automation-in-the-post-covid-19-era/

Raj, Alok, et al. "Supply Chain Management during and Post-Covid-19 Pandemic: Mitigation Strategies and Practical Lessons Learned." Journal of Business Research, U.S. National Library of Medicine, Mar. 2022. Web. 9 Apr. 2024. www.ncbi.nlm.nih.gov/pmc/articles/PMC8776498/

Smith, S. "Manufacturing Insights: Human vs. Robot – Carefully Weigh the Pros and Cons of Automation." BMF, 24 May 2018. Web. 9 Apr. 2024. https://bmf.cpa/2018/05/24/manufacturing-insights-human-vs-robot-carefully-weigh-the-pros-and-cons-of-automation/

Appendices

6.1Project Schedule



Notes

1. Phase one
- Define the project objectives, scope, and deliverables.
- Identify the problem to be addressed and determine the desired outcomes.
- Gather necessary data and information related to the problem. (Maggie, Dylan, Ely)
2. Phase two
- Identify the variables, constraints, and relationships relevant to the problem.
- Formulate a clear problem statement.
- Translate the problem statement into mathematical equations.
- Define decision variables, constraints.
- Implement the mathematical model using suitable software. (Excel, minitab , MATLAB)
- Gather relevant data required for model inputs and parameters.
- Clean the data to ensure accuracy and consistency.
- Validate the data against real-world observations or experimental results.
3. Phase three
- Analyze the results generated by the mathematical model.
- Interpret the findings
- Make any changes and communicate with steakholders for feedback
- Identify limitations, and potential areas for improvement.
- Final report done have it peered review
- Present the results

Figure 10 Project Schedule

6.2 Budget

Budget	
Labor	Student $20/hr Professor $100/hr
Software package	$5/month to a one-time fee of $149.99 per user
Total Budget	$500
Total cost to end user	$0

Table 1 Bill of Materials

Note: The development costs were incurred as part of the senior design project therefor if a company already has Excel the total cost to the end user is $0.

6.3Budget

Failure Mode	Failure Causes	Failure Effects	Likelihood Occurrence (1-10)	Likelihood of Detection (1-10	Severity (1-10)	Risk Profile Number (RPN)	Actions to Reduce Occurrence of Failure
Data input errors	-Human error during data entry - Lack of data validation checks - Misinterpretation of data requirements	-Inaccurate results and decisions - Incorrect evaluation of risks and benefits	5	3	10	150	- Provide training on data entry -Implement data validation checks and error prompts
Calculation errors	-Human error during manual calculations -incorrect use of mathematical formulas	-Inaccurate results and decisions - Misinterpretation of data and analysis - Potentialfinancial or operational losses	4	3	10	120	-Implement automated checks and cross checks for accuracy
Outdated data	-Failure to update data regularly	-impact decision-making -lead to inaccurate	3	3	9	81	- Establish regular data update schedules

Table 2 F1MEA