

DIGITAL TWIN: FACTORY DISCRETE EVENT SIMULATION

by

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A Directed Research Project

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science



School of Engineering Technology

West Lafayette, Indiana

May 2019

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

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ACKNOWLEDGMENTS

Special thanks and acknowledgment to my team, Adam Marshall, Ed Dreyer, Rockey Aye and Weigang Hu. Their expertise and support has guided me through learning about simulation software, discrete event simulation, the digital transformation and where it will be applied in the real world. I would also like to extend another thank you to Dr. Dunlap for his support of this research project, Dr. Dunlap provided top notch guidance while supporting me through a journey that required flexibility off the traditional path. Dr. Dunlap was also able to join us at our factory in Washington State, a special thank you for him making the time to visit as well as to Ed Dreyer and Rockey Aye welcoming him and sharing the day with us.

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GLOSSARY

Cycle Time: How long a product takes to pass through the entire production process (Miltenburg and Sparlin, 1996).

Digital Transformation: Process of moving to “new information and communication technologies” (Loonam, Eaves, Kuman and Parry, 2018).

Discrete Event Simulation: Analysis of a system over time using a sequence of events and constraints. (Dassault, 2018).

Engineering Bill of Materials: Standardized data detailing how a product is has been designed (Hwang, I., Lee, C. and Leem, C, 2010).

Gantt: Operations is a system shown overtime (Dassault, 2018).

Manufacturing Bill of Materials: List of “all parts and assemblies required to build a complete product” that breaks down the end product and components to show how the product is transformed (Dassault, 2018).

Non-Value Added: Unnecessary “activities and process” that do not contribute to the final result (L’Homedieu and Kappeler, 2010).

Precedence: Order of prioritization in operations, the first in the order happens before any others (Dassault, 2018).

Process Plan: List that defines the “the sequence of routing/operations” of the manufacturing bill of materials. (Dassault, 2018)

Takt Time: “German word for tempo” that details the frequency a product moves from one process to the next (Costanza, 1996).

Value Added: Necessary or required “activities or processes that contribute” to the final result (L’Homedieu and Kappeler, 2010).

Work Instruction: Detailed plan of installation routing/operations through both verbal and non-verbal means (Haug, 2015)

ABSTRACT

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 Degree Received: May 2019
 Title: Digital Twin: Factory Discrete Event Simulation
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Industrial revolutions bring dynamic change to industry through major technological advances (Freeman & Louca, 2002). People and companies must take advantage of industrial revolutions in order to reap its benefits (Bruland & Smith, 2013). Currently, the 4th industrial revolution, industry is transforming advanced manufacturing and engineering capabilities through digital transformation. Company X's production system was investigated in the research. Detailed evaluation the production process revealed bottlenecks and inefficiency (Melton, 2005). Using the Digital Twin and Discrete Event Factory Simulation, the researcher gathered factory and production input data to simulate the process and provide a system level, holistic view of Company X's production system to show how factory simulation enables process improvement. The National Academy of Engineering supports Discrete Event Factory Simulation as advancing Personalized Learning through its ability to meet the unique problem solving needs of engineering and manufacturing process through advanced simulation technology (National Academy of Engineering, 2018). The directed project applied two process optimization experiments to the production system through the simulation tool, 3DExperience with the DELMIA application from Dassault Systemes (Dassault, 2018). The experiment resulted in a 10% improvement in production time and a 10% reduction in labor costs due to the optimization.

Keywords: 3DExperience, 3DX, DELMIA, Discrete Event, Factory Flow, Simulation, Digital Twin, Digital Thread, Digital Factory, Digital Manufacturing

CHAPTER 1. INTRODUCTION

Production systems create the products that drive demand, and generate revenue.

Technology is utilized in production systems, and that technology contains data. Companies must manage and utilize that data to better understand their production system. The solution is the digital twin, which allows companies to record, duplicate, model and test data for their production system (Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel, and Harnisch, 2015).

The digital twin allows advanced simulation capability such as discrete event simulation.

Analyzing reliable simulation supports decision making for managing bottlenecks, underutilized resources, and other roadblocks that limit a company's ability to increase rate as product demand rises (Weyer, Torben, Ohmer, Gorecky, Zuhlke, 2016). Knowledge of limitations and their cause allow companies to proactively eliminate production system limitations prior to the need to increase rate. Prior to the digital transformation of the manufacturing space, data was gathered through time studies, job shadowing, excel files and presumptions about the system, providing a blend of manual and digital results. The digital twin captures data from the production system, including takt time, cycle time, and labor operations into a virtual workspace (Grieves, 2014). Utilizing real production system data for the digital twin is critical to produce accurate and actionable simulation results.

Company X, a global manufacturing leader, will be evaluated through this study.

Company X is going through a digital transformation. The digital transformation includes simulation, both creating a visually simulated factory, performing discrete event simulation, and standing up the digital twin and digital thread (Rüßmann et al. 2015). Discrete event simulation models a production system's operations over a period of time based the real sequence of events to create the finished product. Proving the value of establishing simulation software to enable the

digital twin was the goal of the research project. Currently, data is acquired manually out of disparate systems or human interaction causing the analysis of the production system to provide limited results.

Company X produces a complex assembly which was selected for the research project, this complex assembly will be known as Assembly Y. The production system of this assembly is critical to the success of the final product, and has been identified as an area to investigate for limitations at a greater production rate. Company X must commit to further investigate Assembly Y's production system to identify opportunity to support greater production rate. Failure to optimize the Assembly Y production system will prevent Company X from meeting rate, and impact revenue and customer experience.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Industry 4.0

Industry has gone through three revolutions led by “pivotal technological advances” which are “water power, steam power, electricity, motorization and computerization” (Freeman & Louca, 2002). Industry 1.0, 2.0, and 3.0 are how the periods of change are named. Industry 1.0 started during the late 18th century from water power as well as the steam engine to increase manufacturing capability, lower costs and time to transport goods and powered industry (Rosenberg & Trajitenber, 2004). Through the 19th century industry 2.0 brought on mass production capabilities through electricity and advanced tooling which eventually led to Henry Ford’s assembly line (Hull, 1999). During the 1940’s information technology, automation, circuits and software connected assembly lines to bring about Industry 3.0. Industrial revolutions lead to a “crucial period of economic growth” (Bruland & Smith, 2013). Information technology crossed industry and created massive productivity growth, Figure 2.1 shows the relationship between investment in IT and the resulting productivity.

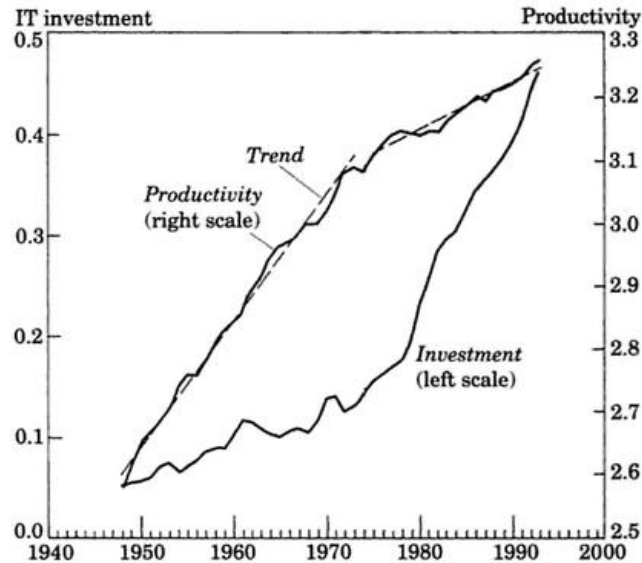


Figure 2.1 Investment in information technology and labor productivity (Greenwood, 1997)

Industrial transformation is on-going. Boston Consulting group states that additive manufacturing, simulation and the internet of things will be the portal to industry 4.0 (Rüßmann, et. al. 2015). Recent predictions show that the automotive industry will receive 9% productivity increases in less than 10 years (Rüßmann et al. 2015). Digital transformation from industry 4.0 will be critical for companies around the world to remain competitive.

2.2 Digital Twin

Industry 4.0 will bring change into the manufacturing space. One key element of industry 4.0 is factory simulation, supported by the digital twin. The “digital twin” will record data in real time, and create a duplicate, allowing experts to create models and design tests to investigate optimal settings (Rüßmann et. al. 2015). The digital twin will capture information from business information systems, the internet of things and artificial intelligence to build this “virtual model of the workspace” (Zbigniew, 2015). Digital twin will disrupt the way that manufacturing and

business is done, optimizing manufacturing lines and driving process improvement through the production system. Gartner research has shown that by 2021, digital twin will be in effect at half of the global companies and result in a 10% gain in company effectiveness (Gartner, 2017).

Adoption of the digital twin will provide business and technical leaders the ability to add flexibility and make company data available to decisions makers. Digital twins will be implemented at different levels of complexity that “vary based on the use case, the vertical industry and the business objective” (Gartner, 2017). Regardless of how a company chooses to pursue the digital twin, if done correctly, productivity improvement will follow.

2.3 Factory Simulation

Factory simulation is a component of the digital twin. Proper factory simulation relies on three key components coming together to create the digital twin. Physical items from the real world, digital products from a virtual workspace, and data systems connected to the digital twin to send information and data about the real world into the virtual workspace (Grieves, 2014). The three items allow users to create “light-weight models”, containing just the essential information, to simulate systems “including their physical behaviors, in real-time” (Grieves, 2014). Figure 2.2 displays a visual example of a factory simulation.



Figure 2.2 Digital Factory Model (Grieves, 2014)

Simulations include key information for the factory environment, including manual and robotic processes and movements (Grieves, 2014). Factory simulation provides feedback of how the real production system operates, without needing to actually run the process through the factory. Simulation supports “engineering and decision-making processes” used to investigate for and prevent manufacturing issues (Weyer, et al, 2016). As factory simulation continues to become more sophisticated, simulation will be used to “strategically support production-related activities, during all steps of the production life-cycle” (Weyer, et al. 2016). Factory simulation is not the only capability brought by the digital twin.

2.4 Process Planning and Model Based Engineering

Process plan dictate the order that operations occur, labor time and resources used (Dassault Systemes, 2018). Correctly defined process plans rely on planners creating a sequential view of the production line, record activity used to product the product, dictate the constraints and cycle time (Dassault Systemes, 2018). Model based engineering is used to acquire reliable information for the process plan. The “process models” clarify what happens, by who and when in the production system (Fischer, 2010). Model Based Engineering (MBE) unites design and manufacturing data to 3D models, and automatically updates them after a change, to create one source of truth for production requirements (Zhu, Li, 2018). Walking away from unreliable manual processes and toward automation is key to move forward in the digital transformation. The “process models” define what happens, by who and when (Fischer, 2010). Model based engineering is integral to simulation the represents the real process.

2.5 Discrete Event Simulation

Discrete Event Simulation is “one of the most popular modeling techniques” that has existed since the 1950s (Robinson, 2005). Discrete event simulation “forecasts system behavior over a period of time to predict future performance” (Ghani, U., Monfared, R., Harrison, R., 2015). Discrete event simulation accomplishes this by monitoring the production systems operation over time using real, ordered events (Robinson, 2004). Since the 1950s, discrete event simulation has dramatically changed to incorporate interactive 3-dimensional modeling, simulation for optimization, virtual reality and the integration of disparate software (Robinson, 2005). Digital twins create a “virtual engineering environment” that drives verification for processes and resources prior to execution in the digital world, which becomes trusted data for discrete event simulation (Ghani, U., 2015). Manufacturing industries need to “configure, validate and optimize their processes to stay relevant in the market (Ming, 2008). Manufacturing leaders will use modern discrete event simulation to make decisions, predict behavior of the production system and allocate resources for current and future rate requirements which will aide market position (Jahangirian, 2010). Modern applications like 3DExperience DELMIA, by Dassault Systemes were developed to make this digital model available to companies, and have discrete event simulation capability (Dassault Systemes, 2018). The applications pull data from trusted physical and digital systems and enact algorithms to complete simulation (Ghani, 2015). Users that call key inputs into simulation applications and use their built-in capability to run discrete event simulation will be able to identify areas of opportunity for the production system and tackle bottlenecks of future rate prior to enacting the rate increase. Proper integration of digital twin that can support a 3D simulation applications discrete event capability that will

provide companies the power to improve existing processes and better prepare for future manufacturing endeavors.

2.6 Conclusion

Industry 4.0 will digitally transform the manufacturing world. Success in the digital transformation is needed to keep pace. Digital transformation provides reliable data from a source of truth that can be utilized to create a digital twin that is capable of factory flow discrete event simulation. Factory flow discrete event simulation will show opportunity to improve productivity in the present and prepare for rate increases for the future. Companies that digitally transform will be prepared to succeed in their production goals.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Environment

The study involve a factory flow discrete event simulation of a manufacturing production system. The facility follows Assembly Y through the production system, from input to output, by using work instructions to show the sequence of the factory. Company X employees include manufacturing engineers, industrial engineers, and mechanics. Employees use work instructions to guide them through the work that must be accomplished to complete Assembly Y. Assembly Y is manufactured using simple and complex tooling, work surfaces, supply carts and storage. Company X wishes to investigate the impact of higher rate demands in the future, as well as process improvement ideas.

3.2 Procedure and Analysis

Discrete event simulation will be accomplished through the creation and use of an actionable and repeatable process. The repeatable process includes:

- Training staff on the simulation software.
- Key contacts and resources needed from the factory that have access to data.
- The part of the production system to be evaluated, selecting this set the scope of the project. One job, one station or up to the entire production system.
- Work instructions from the selected part of the production system, and their cycle time and number of resources working on each item. The production system data was used to make the simulation match the real world cycle time.

- Engineering bill of materials that details how the product was designed, covering parts, sub-assemblies and assemblies.
- Development of a manufacturing bill of materials structure out of the engineering bill of materials, which detail how the product parts, sub-assemblies and assemblies are put together.
- Creation of the process plan from the engineering and manufacturing bills of material, showing the order the product is produced in the real world using work instructions.
- Plant layout and factory flow defined in the simulation software in order to connect the process plan to the factory.
- Execution of the discrete event simulation, which will provide output data.
- Analysis of the results against expectations.

Successful documentation of the above steps will become an actionable and repeatable process for discrete event simulation of a production system. The research project assumed that those conducting the experiment are trained on the simulation software, 3DEXperience and the DELMIA application, from Dassault Systemes (Dassault, 2018).

The data set used by this discrete event simulation will be acquired through evaluating the Assembly Y production system. The scope of the Assembly Y evaluation will cover all of the work in the manufacturing process. Results from the discrete event simulation require a researcher to identify what input information will lead to better evaluation of the system. Assembly Y will use five measures. The measures include, cycle time, takt time, labor unit hours, and value added work and non-value added work and required rate. Cycle time provides

insight as to how the entire production process preforms at various rate demands. Takt time allows deeper evaluation of each process to support the overall cycle time against the planned speed. Labor unit hours are the basis for staff requirements to support the production requirements. Value added and non-value added activity provide immediate process improvement opportunity for labor utilization and eliminating unneeded tasks (ex. walking to long distances). Rate increase shows if the production system can handle demand for more units to be produced. Information Technology and Engineering will utilize the inputs to perform the discrete event simulation of the system. In this research project, cycle time and demand were the items being considered.

Once the executing person has leadership support for the simulation activity, the team will reach out to the factory staff to acquire installation plans, cycle time, takt time, labor unit hours and what labor is value added or non-value added and rate. Key departments to acquire the input data are detailed in Table 3.1.

Table 3.1 Key Departments

<u>Department</u>	<u>Data Point</u>	<u>Source</u>
Industrial Engineering	Cycle Time, Takt Time and Process Plan	Time Studies and work instructions
Manufacturing Engineering	Plant Layout, Production Process	Process Plans, Production System Design

Immediately after acquiring the raw data, the team must import the data into the simulation software. Completing this step required the creation of an engineering bill of materials, a manufacturing bill of materials and process plans in the simulation application.

Inside the DELMIA application, product structure must be created to represent the engineering bill of materials. The product structure represents how the product was designed, and is shown in Figure 3.1

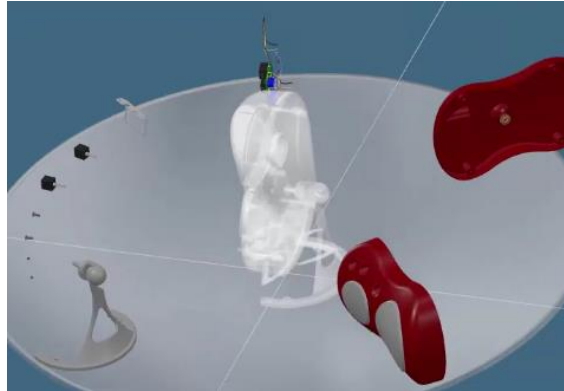


Figure 3.1 DELMIA Product Structure (Dassault Systemes, 2018)

Creating the engineering bill of materials involves the importing of 3D models from modeling software where design engineers created the original product. Next, following the product structure that represents the engineering bill of materials, a user will create the manufacturing bill of materials, typically done by a manufacturing engineer. The manufacturing bill of materials will detail how the parts, sub-assemblies and assemblies come together for the final product. Figure 3.2 shows how the manufacturing bill of materials product structure looks.

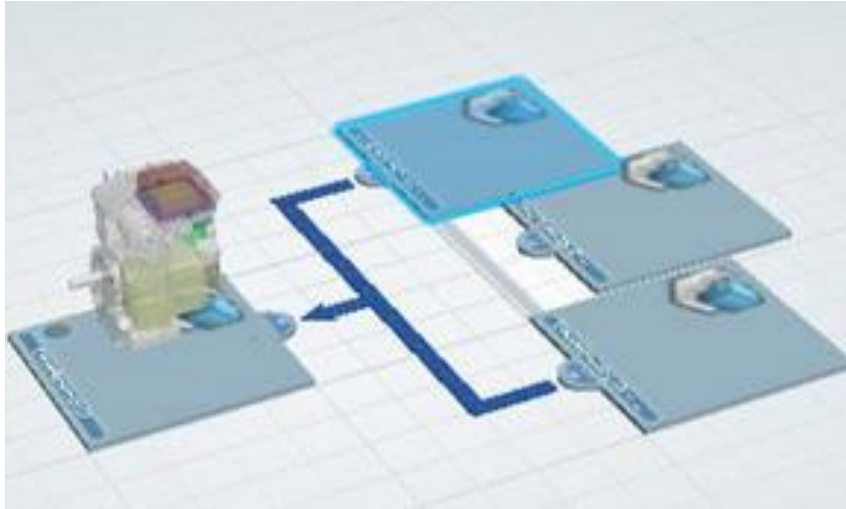


Figure 3.2 DELMIA Manufacturing Bill of Materials (Dassault Systemes, 2018)

Next, a user will build their process plan that shows the real world sequence product is assembled based on work instructions, Figure 3.3 shows an example of a DELMIA process plan.

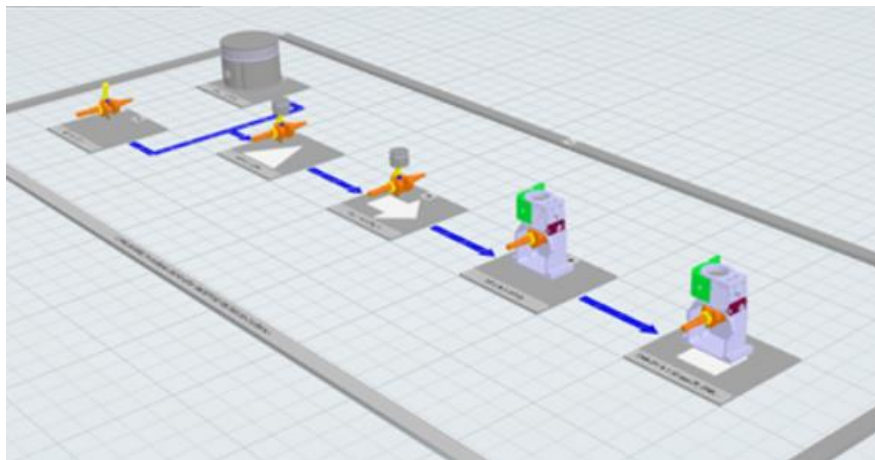


Figure 3.3 DELMIA Process Plan (Dassault Systemes, 2018)

Industrial engineers can be utilized to complete the process plan. Finishing the process plan will allow the simulation application to understand how and what order to complete the jobs. Process planning is critical to prevent a job that has a dependency from being completed before or at the

same time as the dependency. The process plan is also the input area for cycle time and value added and non-value added data.

After completing the process plan, plant layout and factory flow must be defined. Plant layout is the 2D footprint of the plant, with human resources, carts and storage, and models of the product placed. Figure 3.4 shows an example of a plant layout design.



Figure 3.4 DELMIA Plant Layout (Dassault Systemes, 2018)

The plant layout allows the factory flow to be defined. Factory flow connects the plant layout to the process plan and defines how and where the material enters the production system, and how the process plan is completed along the way. Figure 3.5 shows an example of factory flow.

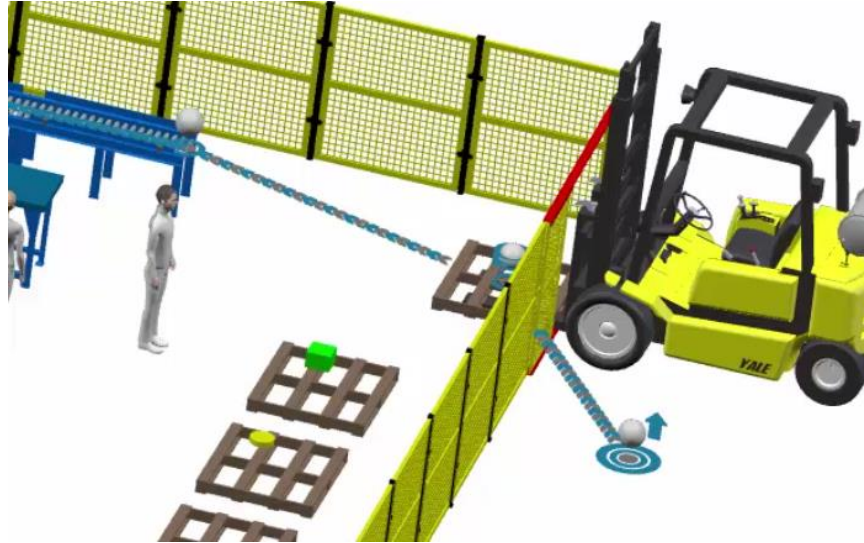


Figure 3.5 DELMIA Factory Flow (Dassault Systemes, 2018)

Completion of the engineering bill of materials, the process plan and the manufacturing bill of materials, plant layout and factory flow will allow discrete event simulation to be run. Figure 3.6 shows a discrete event simulation being run through DELMIA.

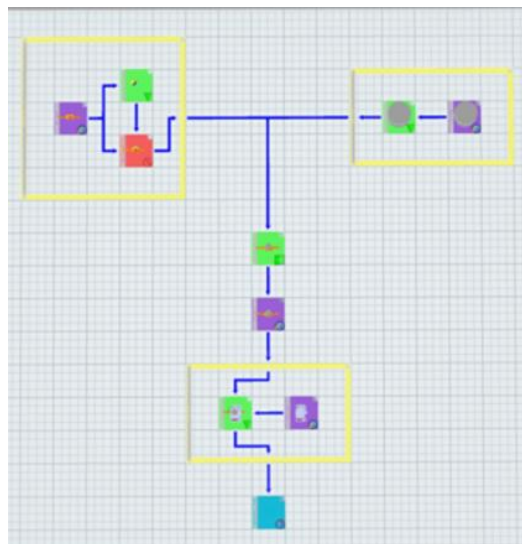


Figure 3.6 Discrete Event Simulation (Dassault Systems, 2018)

The discrete event simulation will show the state of the system matching the real world. System states are displayed by names and color coding in order to help the user digest the information.

Figure 3.7 details the system state colors and names.








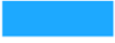










Name of the System State	State	Color
Idle		
Processing		
Transporting		
Wait for Input		
Wait for Output		
Failed		
Empty		
Partial		
Full / No Reorder		

Figure 3.7 System State (Dassault Systemes, 2018)

System state is used to identify areas that carry a risk of bottleneck or inefficient process. As the discrete event simulation concludes, the analysis report is produced. The analysis report creates dynamic charts containing the behavior of the system through the simulation process. The simulation also creates a table based report that displays the results of the simulation based on the inputs.

Analysis of the output data details labor utilization, bottlenecks, labor time spent, amount of value added and non-value added work, takt time and cycle time which can then be measured against the target. Identified off target results will be reported to manufacturing leadership. Bar

graphs will be utilized for leadership report out to visually compare results against the target.

Figure 3.8 shows an example of a bar graph.

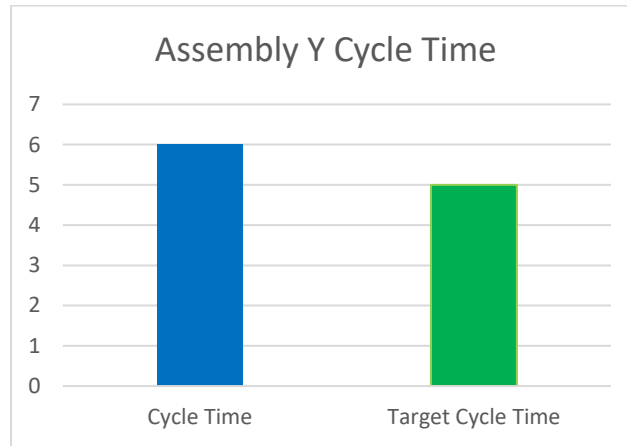


Figure 3.8 Target Comparison

Simulating the factory will be completed over again to test new rate requirements and identify opportunity prior to new production demands. Simulation can be used to see the impact of what a new machine or tool would have on the cycle time after modifying the installation plans.

3.3 Value Proposition

Investing in technology has a positive impact on labor productivity (Greenwood, 1997). Companies will use the digital twin to support factory discrete event simulation. Pursuing the digital twin will allow all evaluation of a production system to happen in the simulation software. Using the simulation software, companies will be able to use the repeatable process defined by this research project to create factory discrete event simulation for existing and new production systems. The repeatable process will allow employees to become self-sufficient when pursuing factory discrete event simulation. Factory flow discrete event simulation can be used to preform system redesign or analysis. In the research project the result of changing sequential operations

to simultaneous operations was tested. Using a example scenario from the industrial engineering team as an experiment, two proposals were analyzed as seen in table 3.2.

Table 3.2 Process Change Proposals

<u>Process Change Proposal</u>	
Current	No Change - operations scheduled to plan
Proposal A	4 operations in position 2 completed simultaneously with no additional labor
Proposal B	3 operations in position 3 completed simultaneously with no additional labor

Using the simulation software to alter the process plan, the researcher made the proposed changes from Proposal A and Proposal B and compared the results to the current process plan. Labor costs, and production time were analyzed for one product flowing through the production system and then extrapolated to future demand. The results of the experiment show a 10% decrease in production time and a 10% decrease in labor costs for one product. Extrapolating this up to a demand of 70 products resulted in a benefit of production time that was 11 days quicker and a \$6723 reduction in labor costs.

Beyond the calculated benefits, the digital twin and digital thread being supported by the simulation software assist the company in other way. First, it creates one single source of truth for Company X's manufacturing data through the digital thread. Second, any updates made to a piece of the data are immediately reflected in all related data due to model based engineering. Thirdly the factory flow simulation provides a visual representation of the factory to support design and empower leaders to make informed decisions.

CHAPTER 4. RESULTS

4.1 Initial Results

Digital twin factory modeling to preform factory discrete event simulation allows companies to test the impact of a change in the production system without altering the real world (Rüßmann et al. 2015). Utilizing simulation software, a digital model can be created to capture cycle time, takt time, labor utilization and manage process planning (Grieves, 2014). The results portion of this research project are divided into two sections. The first section will cover how the source data was translated into the simulation software to create the factory flow and preform the discrete event simulation. The second section will report the simulation and compare them to real world targets and detail how changing factors within the simulation impacts the result of the factory flow discrete event simulation.

4.2 Section One

Data was acquired from the industrial engineering and manufacturing engineering teams at Company X. Data acquired included the work instructions for the operations through the production process. Work instructions included cycle times, and the sequential order of the work. Each data point was provided by different spreadsheets, the data supplied in one file. Using the collected information, the engineering bill of materials was created to represent the design of the product, shown in figure 4.1, for this report, the product is represented by a sphere.

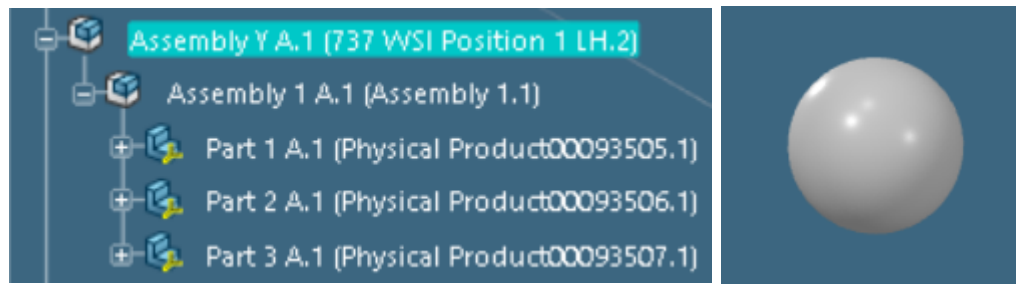


Figure 4.1 Assembly Y Engineering Bill of Materials

The engineering bill of materials was then referenced in the creation of the manufacturing bill of materials in order to account for all parts that must be included in the manufacturing process.

The work instructions defined the manufacturing bill of materials by work package, which was used to define the assembly and parts in the bill of materials. A segment of the manufacturing bill of materials is shown in figure 4.2.

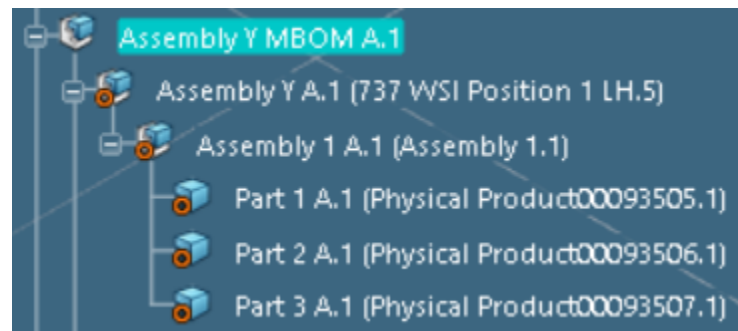


Figure 4.2 Assembly Y Manufacturing Bill of Materials

Work instructions were used to create the process plan. The information was input as a system, broken down by operations, each operation represents a work instruction and contains the cycle time data point. The process plan structure is shown in figure 4.3.

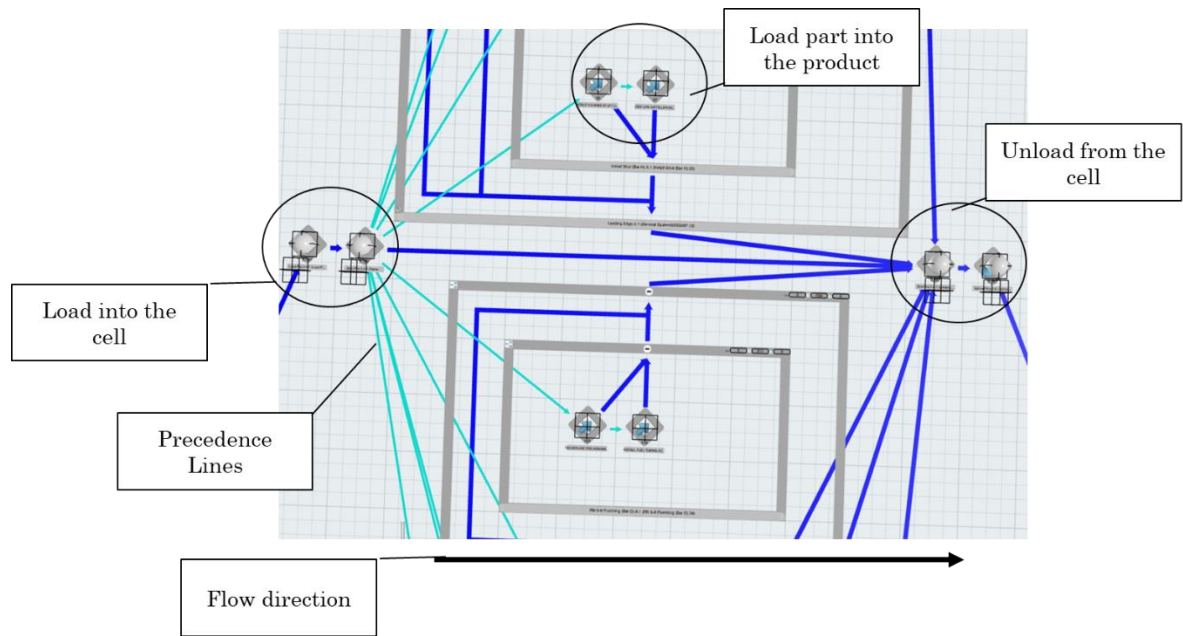


Figure 4.3 Assembly Y Process Plan

The light blue lines that travel point to point represent a precedence relationship, where the source must complete before the result can begin, this is used to show work that occurs simultaneously. The solid blue line represents product flow, product either being installed for moving through the production system. The process plan, and plant layout were built using 3D representations of equipment and workers along with a handmade 2D representation of the factory floor. Figure 4.4 shows the plant layout design and the resources included in the first cell.

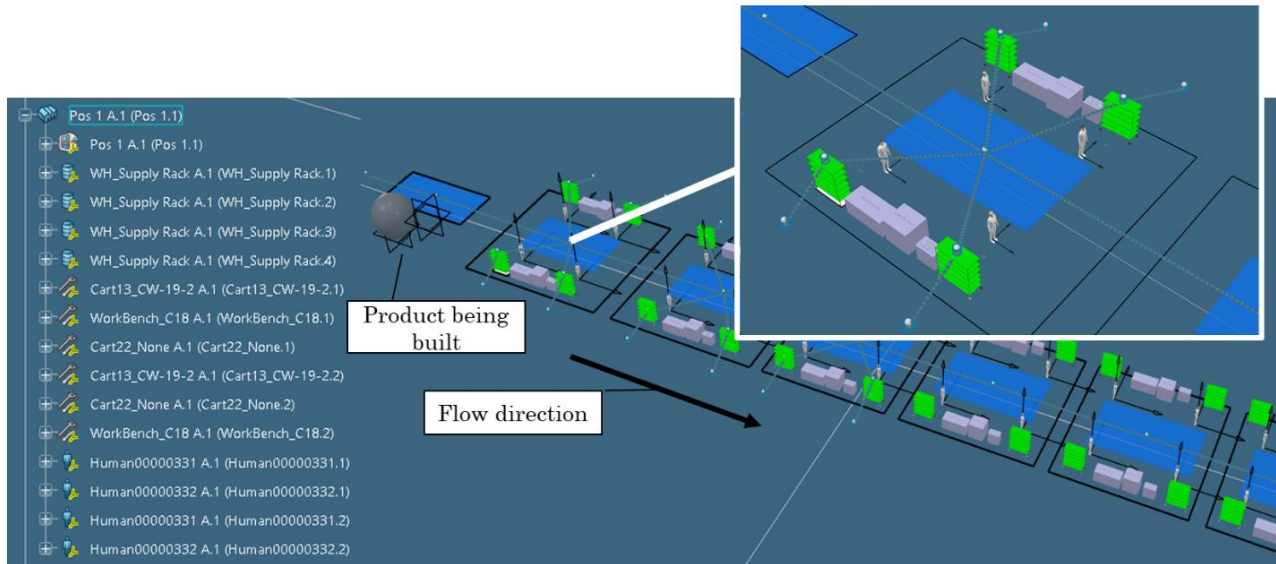


Figure 4.4 Assembly Y Plant Layout and Cell One Resources

Using the completed plant layout design, products were assigned zones in the factory to define the factory flow. Resources (storage), was then linked to parts, and workers assigned to operations in the process plan to complete the work instructions. Figure 4.5 shows a zoomed in view of one cell, showing parts flowing from storage into the product as it follows the factory flow.

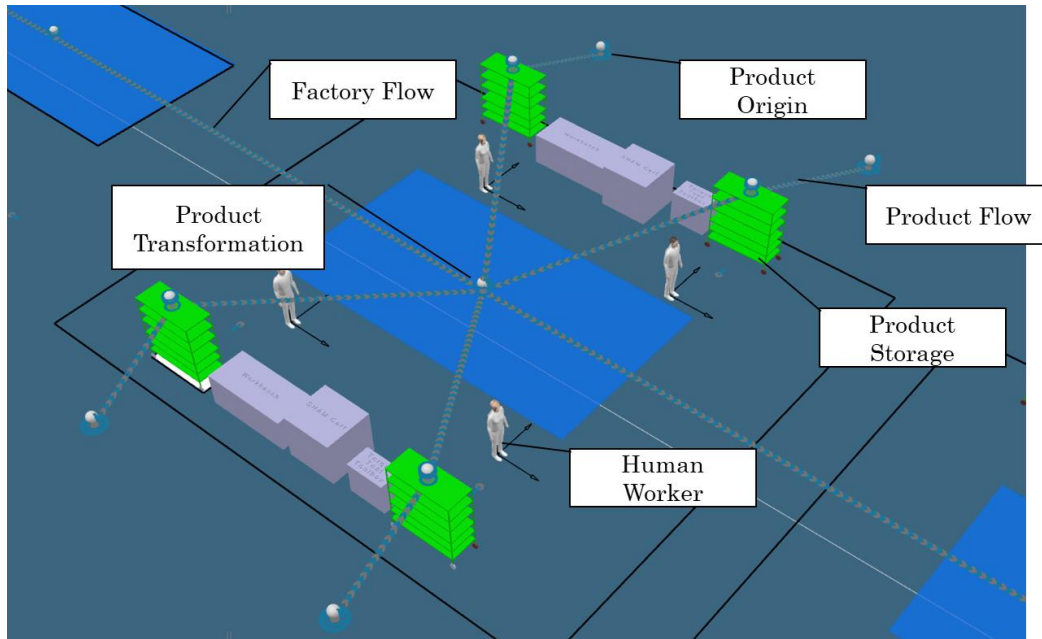


Figure 4.5 Factory Flow Floor View

Completion of the engineering and manufacturing bill of materials, the process plan, the plant layout design, and factory flow defined made discrete event simulation possible, allowing a visual, 3D representation of the factory flow and output data to analyze.

4.3 Section Two

Discrete event simulation uses planned operations, cycle time and resources to monitor a production system as the events are completed (Robinson, 2004). Section two will compare the real world plan against the results shown in and the discrete event simulation. To aide in mimicking the real world plan, workers in the simulation are set to 100% utilization, meaning they are working on the task at hand 100% of the time throughout the day. The simulation also only runs one product through the production system, cells go idle if they are not working on the product that is being passed through the system.

Proving that the simulation can “strategically support production-related activities, during all steps of the production life-cycle” requires an accurate digital twin (Weyer, et al. 2016).

Using the Gantt chart showing in figure 4.4 the team was able to gather the cycle time for each cell. The results of the process planning in the simulation were analyzed for the first three cells. The cycle times are shown in figure 4.7 and represent the planned cycle time versus the simulation results.

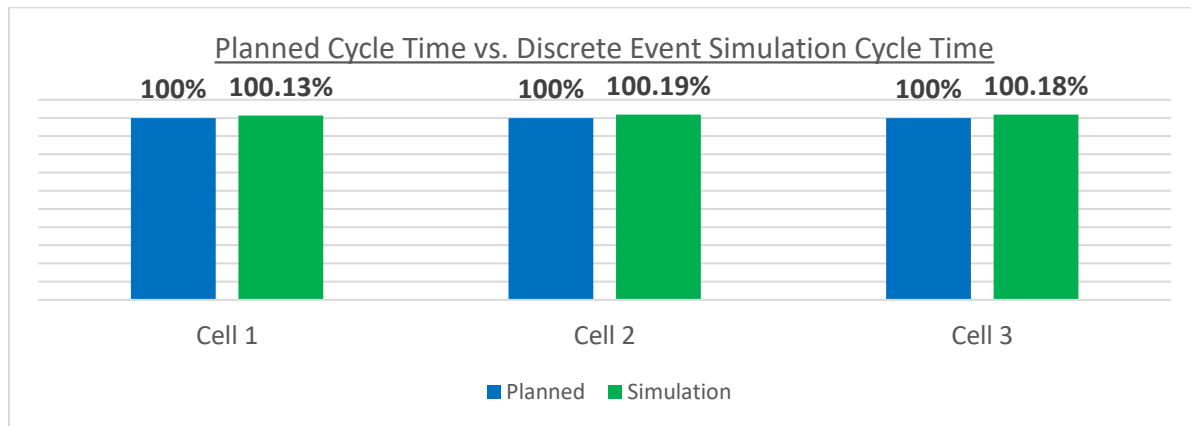


Figure 4.6 Cycle Time Cell 1 to 3: Planned vs. Simulation

The results found in Figure 4.7 show that the simulation was within 0.2% of the real process planning time. The cause of the difference was identified to be caused by a default time being set in the simulation software for how long it takes to prepare a product to move from one cell to another, and how long it takes to initiate the next cell.

Discrete event simulation provided a report out of activity in the production system. The report out contains data that can be used to analyze the production system including worker and robotic utilization rates, worker travel time, time spent waiting, and other data points. When discrete event simulation was used to analyze the entire factory, you can immediately see the impact that changing the process plan and work instructions had on the production system's production rate with the precedence and product flow considered, thanks to the digital thread. The digital thread feature was tested by altering the process plan to be representative of a process improvement activity.

In this hypothetical test, it is assumed that Company X wants to increase the production rate on Assembly Y. In order to do so, process improvement activity was completed at the company, and the industrial engineering team offered up two options in order to improve rate. Table 4.1 shows the suggestions from the industrial engineering team.

Table 4.1 Process Change Proposals

<u>Process Change Proposal</u>	
Current	No Change - operations scheduled to plan
Proposal A	4 operations in position 2 completed simultaneously with no additional labor
Proposal B	3 operations in position 3 completed simultaneously with no additional labor

Both ideas involved completing improving the assembly process to complete work simultaneously rather than sequentially. The process plan was altered in the simulation software to reflect the options suggested by industrial engineering. Figure 4.8 shows the impact that making the process change had on the production time. The current process is shown in grey, improvement idea A is shown in blue, and improvement idea B is shown in green.

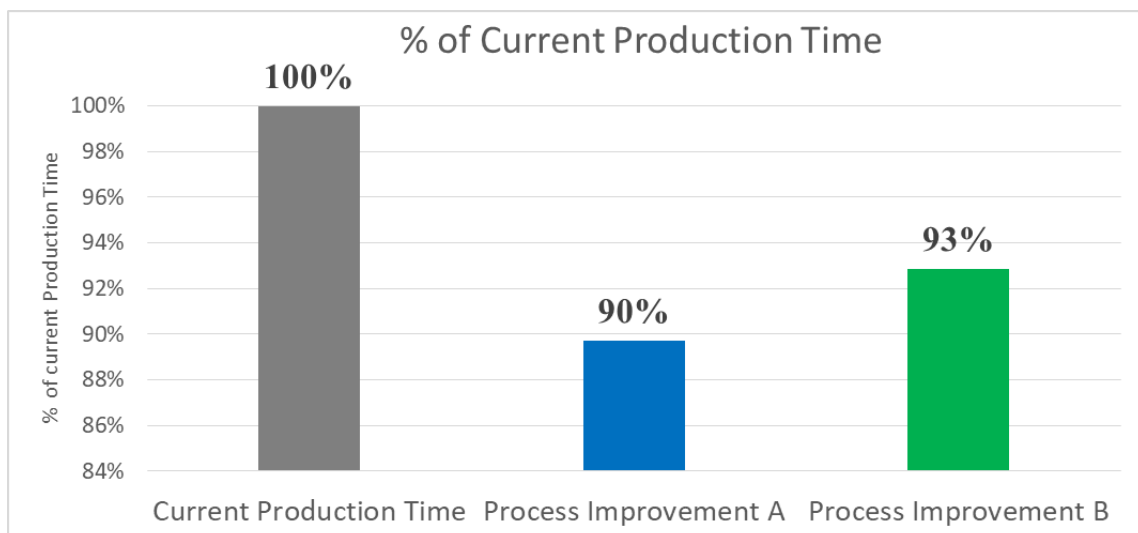


Figure 4.7 Production Time Results

Figure 4.9 shows that process improvement plan A results in a 10% decrease in production time and process improvement plan B results in a 7% decrease in production time. Further analysis was conducted to see the impact of the changes on labor costs. Figure 4.9 show the percent change in labor costs after the process plan changes were implemented.

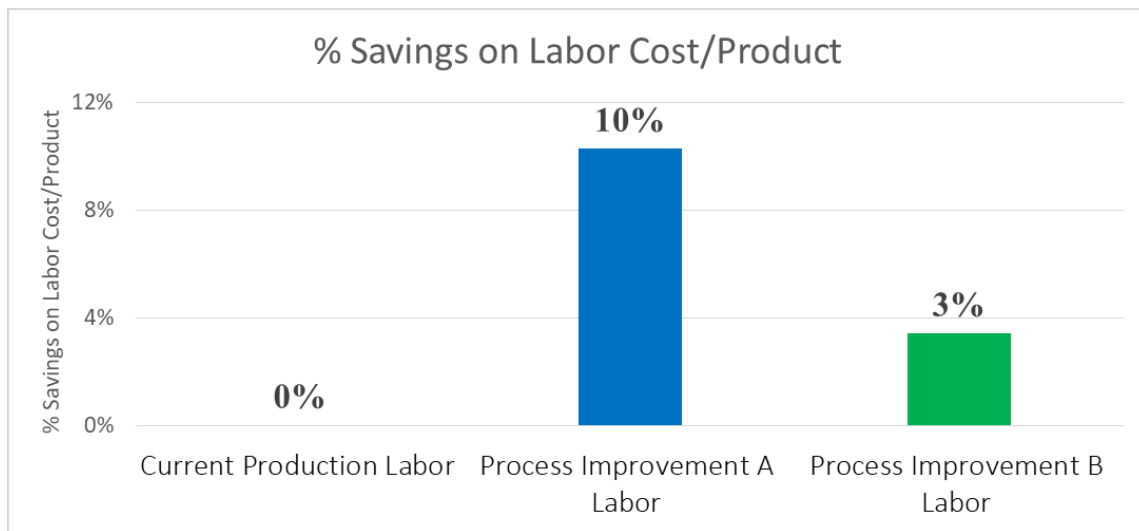


Figure 4.8 Labor Cost Results

Figure 4.10 show that process improvement plan A reduced cost by 10% and process improvement plan B reduced costs by 3%. The results from each experiment show that process improvement A is the best choice, resulting in a 10% productivity increase and a 10% cost decrease.

The previous experiments for production time and labor costs show the impact to the system after producing one product. To better fit the real world, the data was extrapolated to represent the production of 40, 50, 60 and 70 products for both the production time and labor cost. Labor costs were analyzed using the mean hourly wage of \$25.69 for industrial machinery

mechanics (Bureau of Labor Statistics, 2018). Figure 4.10 details the production time in days at the tested demand levels.

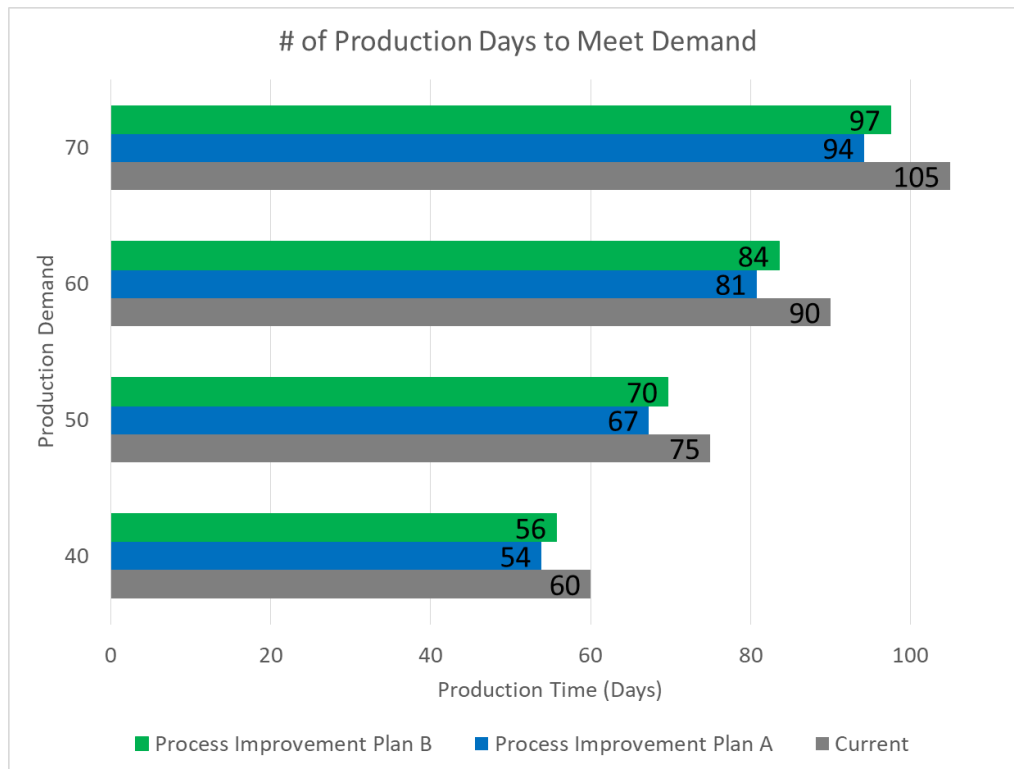


Figure 4.9 Production Time to Meet Demand (Days)

Figure 4.11 details labor costs at the tested demand levels in dollars.

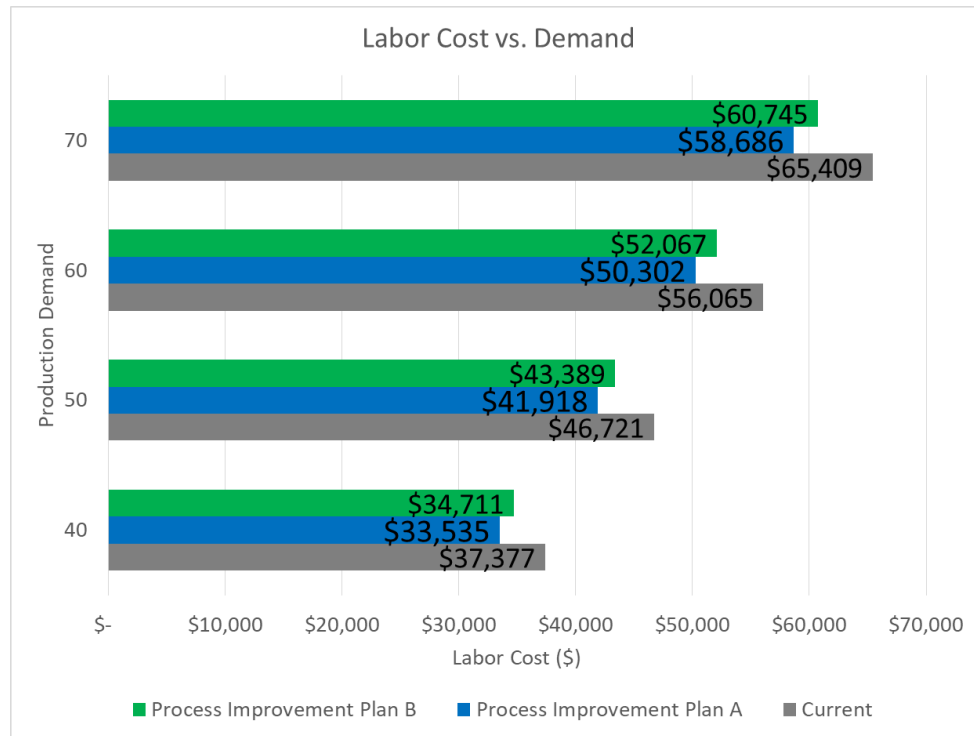


Figure 4.10 Production Time to Meet Demand (Days)

The results of figure 4.11 and figure 4.12 show the production show that as demand reaches 70 products, process improvement A results in an 11 day decrease in production time and a labor savings of \$6,723. The results show that process improvement A is the optimal process improvement plan for Company X. Process Plan modification in the simulation software followed by numerical analysis of the results allows engineers to test ideas quickly and see the impacts on the production system as it is reflective of the real world.

The results of the experiments on the digital model prove the value and power of the tool for production system improvements and cost analysis. The ability to automatically roll any changes up to the discrete event simulation allows quick analysis of the production system, driven by the digital thread. Results from the discrete event simulation can be used for “engineering and decision-making processes” including process improvement, cell design,

workforce planning, and utilization analysis (Weyer, et al, 2016). It is worthwhile for Company X to pursue digital twin and factory discrete event simulation enterprise wide.

CHAPTER 5. SUMMARY, CONCLUSIONS, RECOMMENDATIONS

5.1 Summary

Factory flow discrete event simulation can mimic the real world. Creating a digital twin for factory flow discrete event simulation allows a company the ability to test the existing production system configuration, process change, rate increases and see the system reacts. Digital twin simulation is done using one single source of truth, the digital twin which provides reliable, real world data for evaluation. In this project a test was completed to see the impact of process improvement initiatives and rate increase, showing how investment in reducing the cycle time of a process or raising rate requirements will impact production. The project provides value to the body of knowledge around discrete event simulation, industrial engineering, information technology and how it can support companies as they move through the digital transformation to support a digital twin and digital thread

5.2 Conclusion

Findings from the research project relate closely to the review of literature on Industry 4.0, Digital Transformation, Discrete Event Simulation, and Factory Simulation and Digital Twin. The findings correlate to the literature review by showing a real world application of industry 4.0 and a company experiencing the digital transformation. The project uses the discrete event methodology to preform factory simulation with a digital twin.

The research project was not without limitations. Throughout the development of the project, there was difficulty acquiring sensitive information. Progress was delayed as approvals were required, and the researcher needed to wait for their new job role to begin in order to pursue the topic. The researcher also had to learn the simulation software with no background knowledge,

as well as configure their software to be capable of running the simulation. The time required to train in the software resulted in the scope of the project being minimized in order to provide actionable results during the project timeline. Minimization included:

- Viewing the system at the work instruction level, not specific operations completed by workers.
- Default process time assigned to loading/unloading operations before moving between cells
- Assigning a worker pool rather than labor to specific work.
- Creating simplified 3D data for the bill of materials in order to minimize complexity and the need for 3D models

These limitations led the research project to its current state. The findings of the project are in agreement with the research area, and help put the digital twin and factory flow discrete event simulation into perspective. The project helps readers understand basic capabilities of the digital twin, particularly when lacking fully detailed plans. The business case is supported as the project gives opportunity to visually see how factory flow discrete event simulation works in a business setting. Results were valid as they report the same cycle time as the input data and follow the process plan provided by the company. There is additional opportunity to add further details, including the specific operations workers complete and the exact number of workers at each station. The research project is useful for industrial engineering, management, manufacturing engineering, production engineering, and new product development. Training the company engineers on the simulation software can lead them away from manual discrete event simulation and allow the allocation of more resources to factory flow discrete event simulation and engage simulation at all production system locations.

5.3 Recommendations

Future research is needed on the subject of factory flow discrete event simulation. The research process has led to questions on how to implement factory flow discrete event simulation on a larger scale. These questions include how to get all the needed data, how to import 3D models, the best way to train the team, and what other capabilities does the simulation software have? In order to fully explore these questions, a larger team must be established with access to data and supplier resources. Doing this will allow a company to fully explore and test the simulation software's capabilities. It is recommended by the researcher to model an existing factory at the deepest operational level in order to complete a full and accurate digital twin. It will also worthwhile to apply this capability to a new product using estimates and expertise from technical people. Using the knowledge gained in these efforts can establish a template to create structure for future simulation. Companies can use the experience of creating these initial simulations to train staff and prepare for mass adoption of the application across the company.

Using cycle time and input from experts as the confidence interval readers can believe that the findings accurate as the digital twin results in identical cycle time and process sequence compared to the real world with the exception of loading and unloading time. Issues and outcomes that can be generalized across companies are access to data, time available, training on the application. Clean data, accurate times, and proper training in the simulation software can result in improved factory flow discrete event simulation. Current companies using this simulation software including Safran, Honda Power Products, Locomachs, Embraer and more (Dassault, 2019).

The researcher recommends trying the simulation tactic with new product development, building it up as the product is conceptualized. Doing so will allow better interpretation of data and how real world production system will operate. On new programs, factory flow discrete event

simulation will provide greater confidence production system design by allowing digital testing to occur before making physical investment. For existing products, production systems should be modeled to provide factory flow discrete event simulation in order to gain the ability to analyze the production system given proposed rate increases or process changes.

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