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Performance Evaluation Of A Label Manufacturer Using Simulation Modeling

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PERFORMANCE EVALUATION OF A LABEL MANUFACTURER USING SIMULATION MODELING

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DEDICATION

This thesis is dedicated to my parents, brothers & sister, grandmother, girlfriend, and family for all their support throughout my educational process.

PERFORMANCE EVALUATION OF A LABEL MANUFACTURER USING SIMULATION MODELING

by

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ABSTRACT

Currently, the Supply Chain has been affected by freight prices, material scarcity, demand forecasting, port congestion, and digital transformation which are causing high lead times and delaying deliveries in all industries, but specifically in the labeling/printing industry. The industry is currently affected by the lack of new research improvements, optimization methodologies, supply chain disruptions, and technologies implementations within the label industry.

Labeling /Printing industry has been out in business for more than 50 years, where labeling technologies such as Flexographic, Digital, and Die Cutting have advance in performance, effectiveness, complexity, and dependability over the last years. The implementation of a Discrete-Event Simulation (DES) with Simulation Modeling Intelligent Objects (SIMIO) software will model the behavior and performance of each process and system by predicting the results system performance over time, system interactions, and tracking statistics to measure and compare performance. The input data selected for the model are cycle times, setup times, lead times, product ID, roll footage, machines, processes, and systems, to simulate the accurate simulation. Input data is analyzed with Stat: Fit Distribution algorithms and Excel Analyzer programs utilized to approximate data. Outputs are known to be results, results will be treated to implement scenarios will improve the overall process and system. This research will focus on the implementation of a SIMIO DES system will model virtual and real-world scenarios, while inputting measures will improve the overall flow of setup times, lead times, cycle times, process flow, and number processed. The research will assist in understanding the current manufacturing process with performance capacity enhancements that will improve the overall flow of setup times, schedule utilization, process flow, and number processed.

TABLE OF CONTENTS

ACKNOWLEDGEMENT v

ABSTRACT vvi

TABLE OF CONTENTS vii

LIST OF TABLES ix

LIST OF FIGURES x

LIST OF ILLUSTRATIONS xii

CHAPTER 1: INTRODUCTION 1
- Labeling Industry 2
  - Flexographic Technology 3
  - Digital Technology 3
  - System and Simulations 4
  - SIMIO 5

CHAPTER 2: LITERATURE REVIEW 7
- Labeling Industry Methodologies 7
- Discrete-Event Simulation Methodology 7

CHAPTER 3: EXPERIMENTAL DESIGN 11
- Case Study Description 11
- Model 12
- Data Attributes 14
    - Data 14
- Model Assumptions 14
- SIMIO Model Design 18
  - Facility Design 18
  - Source 19
  - Server 19
  - Sink 24

CHAPTER 4: RESULTS AND FINDINGS 25
- SIMIO Verificaiton and Validation Final Modeling 25

Experiments 28
SIMIO Results 31
Main Effect Plot 33
Main Effect Plot: Standard Week for Machines Schedule Utilization 33
Main Effect Plot: Scale Factors for Machines Schedule Utilization 38
Main Effect Plot: Scale Factors for Machines Number Processed 42
Main Effect Plot: Scale Factors for Sink Number Processed 46
Incrementation of the Rate Scale Factor in Current Scenario..48
CHAPTER 5: CONCLUSION 51
Future Work 52
REFERENCES 53
VITA… 56

LIST OF TABLES

Table 1.1: Research Acronyms. 6

Table 2.1: Literature Review 10

Table 3.1: Resources and SIMIO Interpretation. 12

Table 4.1: SIMIO Input Parameters 14

Table 5.1: Sinks number processed per machine 29

Table 6.1: Number processed per machine with replications 31

Table 7.1: Schedule Utilization per machine with replications. 32

Table 8.1: Schedule Utilization Rate Scale Factor of 3 per machine 32

Table 9.1: Orders Number Processed Rate Scale Ractor of 3 per machines. 49

Table 10.1: Orders Number Processed Rate Scale Factor of per sink 50

Table 11.1: Orders Number Processed Rate Scale Factor of per sink 50

LIST OF FIGURES

Figure 1.1: Types of Labels and Markets 3

Figure 2.1: Labeling Manufacturing Process. 11

Figure 3.1: Demand for 8 months in manufacturer 13

Figure 4.1: Stat: Fit Statistical Analysis 17

Figure 5.1: Stat: Fit Analysis Example 17

Figure 6.1: Source Object Input Data 19

Figure 7.1: Flexographic Server Object Input Data 20

Figure 8.1: Rewinder Server Input Data 21

Figure 9.1: Model State Variables 21

Figure 10.1: Count = State Variable + 1 21

Figure 11.1: Output Destination Path 22

Figure 12.1: Before Wash Process Setup Time Expression 22

Figure 13.1: After Wash Process Setup Time Delay Step. 23

Figure 14.1: Delay Step: Setup Time Process Expression 23

Figure 15.1: Material Properties 23

Figure 16.1: Produce and Consume Step 24

Figure 17.1: Simulation Model Development Phase Implementation. 26

Figure 18.1: Simulation Properties 29

Figure 19.1: SIMIO Experiments with Replications 29

Figure 20.1: SIMIO Experiments with 20 Replications 30

Figure 21.1: Model Results without Replications 30

Figure 22.1: Model Results with Replications 31

Figure 23.1: Main Effect Plot for Machine D Schedule Utilization (%) Graph 34
Figure 24.1: Main Effect Plot for Machine M Schedule Utilization (%) Graph. 34
Figure 25.1: Main Effect Plot for Machine M Schedule Utilization (%) Graph 35
Figure 26.1: Main Effect Plot for Machine J Schedule Utilization (%) Graph 35
Figure 27.1: Main Effect Plot for Machine L Schedule Utilization (%) Graph 36
Figure 28.1: Main Effect Plot for Machine S Schedule Utilization (%) Graph.......................... 36
Figure 29.1: Main Effect Plot for Rewinder Schedule Utilization (%) Graph 37
Figure 30.1: Main Effect Plot for Rewinder A Schedule Utilization (%) Graph 37
Figure 31.1: Main Effect Plot for Machine D Schedule Utilization (%) with Scale Factors 38
Figure 32.1: Main Effect Plot for Machine M Schedule Utilization (%) with Scale Factors....... 39
Figure 33.1: Main Effect Plot for Machine F Schedule Utilization (%) with Scale Factors 39
Figure 34.1: Main Effect Plot for Machine J Schedule Utilization (%) with Scale Factors......... 40
Figure 35.1: Main Effect Plot for Machine L Schedule Utilization (%) with Scale Factors........ 40
Figure 36.1: Main Effect Plot for Machine S Schedule Utilization (%) with Scale Factors 41
Figure 37.1: Main Effect Plot for Rewinder Schedule Utilization (%) with Scale Factors.......... 41
Figure 38.1: Main Effect Plot for Rewinder A Schedule Utilization (%) with Scale Factors...... 42
Figure 39.1: Main Effect Plot for Machine M Number Processed (orders) with Scale Factors... 42
Figure 40.1: Main Effect Plot for Machine J Number processed (orders) with Scale Factors..... 43
Figure 41.1: Main Effect Plot for Machine D Number processed (orders) with Scale Factors.... 43
Figure 42.1: Main Effect Plot for Machine F Number processed (orders) with Scale Factors 44
Figure 43.1: Main Effect Plot for Machine L Schedule Utilization (orders) with Scale Factors . 44
Figure 44.1: Main Effect Plot for Machine S Schedule Utilization (orders) with Scale Factors . 45
Figure 45.1: Main Effect Plot for Rewinder Schedule Utilization (orders) with Scale Factors ... 45

Figure 46.1: Main Effect Plot for Rewinder A Schedule Utilization (orders) with Scale Factors 46

Figure 47.1: Main Effect Plot for Warehouse Number processed (orders) with Scale Factors.... 47

Figure 48.1: Main Effect Plot for End Product Number processed (orders) with Scale Factors.. 47

LIST OF ILLUSTRATIONS

Illustration 1.1:Input-Process-Output-System 13

Illustration 2.1: Thesis Process Map 13

Illustration 3.1: 2-D Visual Representation of the SIMIO Model 17

Illustration 4.1: 2-D Visual Representation of the SIMIO Model 27

Illustration 5.1: 3-D Visual representation of the SIMIO Model 27

CHAPTER 1: INTRODUCTION

Simulation modeling is a recent digital representation technology intended to represent physical objects, processes, or services in a system. [13] The labeling industry has diversified technologies over the last years and is looking for new approaches to handle manufacturing processes, physical objects representation, and services. The crucial start for a labeling industry is implementing intelligent technologies to improve the overall manufacturing setting.

The labeling industry supply chain has been affected by freight prices, material scarcity, demand forecasting, port congestion, and digital transformation which causes high lead times and delivery. [23] As of now, an estimated time of 38 days and 45 days is expected for customers to discharge cargoes from ports of entry in the United States. [23] As a result, new services such simulation models, freight carriers, transportation routes, and resources. As side from all the disruptions, the industry is affected by the lack of new research improvements, optimization methodologies, supply chain disruptions, and technologies implementations. Labels used in the manufacturer are considered to have complexity, variability, and customization. The methodology implemented will address variability, complexity, and customization parameters.

The purpose of this research is to study a local label manufacturer utilizing a Discrete-Event Simulation (DES) methodology that will assist in understanding the current manufacturing process along with performance capabilities enhancements. The study will identify how many orders can the manufacturer process with the present and proposed scenario in connection with reducing idle time, maximizing the number processed orders of each labeling printers, measuring the schedule utilization of labeling printers, and aiding stakeholder with the current and potential scenarios. The subsections below will discuss the introduction to the label industry, flexographic technology, digital technology, and SIMIO.

LABELING INDUSTRY

The labeling industry has been in business for more than 50 years. Labeling technologies such as Flexographic, Digital, and Die-cutting have advanced in performance, effectiveness, complexity, and dependability over the last years. According to the Smithers company statistics, a growth rate of $13 billion (1.6%) expected in 2025 for the flexographic industry base on the compound annual growth rate (CAGR) due to the increased demand in packaging print. [20] According to the smithers statistics, expected discoveries are technological developments, shorter and customizable runs in consumer goods and packaging, and sustainable measures. [20]. The flexography industry has expanded to different sectors such as automotive/recreational vehicles, medical devices, healthcare, government, retail, aerospace, electronics, appliances, and industrial products. Popular technologies utilized are flexography printing, digital printing, laser printing, thermal transfer printing, DOT Matrix Printing, and screen printing. Printers used in the labeling industry is subject to printing in different properties of material rolls in labels. Figure 1.1 shows the types of materials in label currently used in the labeling industry. All kinds of label material have other characteristics, properties, and constraints when selecting a label. This research will address only two leading technologies, flexography, and digital printing. All technologies discussed above have different functionalities, advantages/disadvantages, costs, lead times, setup times, and efficiencies.

TYPES OF LABELS
UNIVERSAL CODE LABELS
TAMPER EVIDEN LABELS
POLYESTER
PACKAGING (METALLIC)
THERMAL TRANSFER LABELS
CUSTOME SHAPE LABELS
ULTRAVIOLET COATED LABELS

MARKET:
AUTOMOTIVE AND RECREATIONAL VEHICLES
MEDICAL DEVICE
HEALTHCARE
GOVERNMENT
ELECTRONICS
FOOD AND BEVERAGES
FURNITURE
INDUSTRIAL PRODUCTS

Figure 1.1: Types of Labels and Markets

Flexographic Technology

Flexography printing is a traditional method for printing labels at a high-speed level. Throughout decades flexography has been the recurrent technology used by the labeling industry due to its high speed, versatility, low-cost maintenance, consumables, cost-efficient, secondary finishing, fast production, color precision, in line foiling available, and large low-cost printouts.

Nonetheless, flexography technology has encountered limitations, such as complexity, lengthy prepress, and operational experience.[1]

Digital Printing Technology

As time goes by, technologies become more sophisticated. The digital printing system can print labels instantaneously in colors, formats, and shapes. [1] Digital printing technology is a recent technology brought to the market known for its fast setup, less image processing, higher resolution images, easier to change/update labels with no extra setup cost, lower cost for short term, quick turnaround, low-volume jobs, increased consistency, variable data handing, and touchless. It is also important to mention the inabilities of utilizing digital technology, such as Ink-limitations, limited in-line processes, and lower durability.

Flexographic and Digital printing have various flexibilities. The implementation of systems and simulation will benefit the industry in short and long term.

System and Simulations

Simulations are known to study and improve the "systems of people, equipment, materials, industries, and procedures." [14] A system is a set of components working together for the same purpose. [14] However, knowing the initial position of a system, whether the objective is to experiment with an existing system or experiment with a model system.

Defining the process structure of a system will help define the development of a model. As in this research, the purpose is to assess a discrete-event simulation system with a SIMIO application. This research will address the following path: Model of a System> Mathematical Model> Simulation>Discrete>Discrete-Event Simulation>SIMIO. [22] In the study by Sweetser, describes Discrete-Event Simulations models as dynamic, discrete, and stochastic. [22] Overall, the purpose of the Figure 2.1 is to integrate Discrete-Event simulation models into a system by identifying all paths.

Simulation models consider model-based systems with the opportunity to implement improvement tools: Lean, Six Sigma, value stream maps, spaghetti diagrams, process flow charts, concept maps, 5-why analysis, KPIs, and more. Improvement tools described above are visual routes to describe and analyze systems for better decision-making. Nowadays, computational modeling is the approachable technique. Modeling technique other alternative is by hand, but cost, time, and resource effective.

SIMIO is a tool to conduct computational modeling. The intent is to interact within the system by adding a logical description to the model. The computational simulation alternative is to replicate the model; each time the model runs, the systems running behind the scenes with statistical information to comply with system logic.

Verification and Validation are essential components of the model logic, defining the accuracy of results and model logic of the research. Validating the model should approximate the nearest value in results to obtain a confident result.

The decision to use such techniques is in line with the project's aim to evaluate the labeling manufacturer scenario with the SIMIO application technique.

SIMIO

The aim of adopting SIMIO software for this research is to evaluate and improve a manufacturing industry utilizing the capabilities of SIMIO software. SIMIO software founded in 2005 by C. Dennis Pegden, Ph.D. SIMIO stands for Simulation Intelligent Modeling Framework based on Intelligent Objects. [14] SIMIO aims to solve complex systems solutions for design, emulation, and production schedule systems.[17] The power and benefit of simulating systems, creating production systems, and making decisions using SIMIO are trusted by 500 fortune companies such as Ford, Boeing, Lockheed Martin, Northrop Grumman, and Johnson & Johnson. [17] Currently, fortune companies, manufacturing companies, and government support the application of SIMIO to represent and support their daily activities. The advantage of adhering to a SIMIO model is making better decisions, conducting a real-time risk analysis, and solving complex problems. [17]

Table 1.1: Research Acronyms

Acronyms	Name
CAGR	Compound Annual Growth Rate
DES	Discrete-Event Simulation
DMAIC	Define, Measure, Analyze, Improve, Control
FMEA	Failure Mode Effect Analysis
FPY	First Pass Yield
KPI	Key Performance Indicators
MEP	Main Effect Plot
NP	Number Processed (orders)
SIMIO	Simulation Modelling Intelligent Objects
SU	Schedule Utilization
OEE	Overall Equipment Effective
OTD	On-time Delivery
PR	Production Route
QFD	Quality Function Deployment

CHAPTER 2: LITERATURE REVIEW

The labeling industry has been in business for decades. Research initiatives conducted in industry aims to develop more sophisticated technologies. The labeling industry studies are in labeling industry, Discrete-Event Simulation (DES) methodology and Key Performance Indicators (KPI for this research.

LABELING INDUSTRY METHODOLOGIES

Labeling industry is facing constant challenges such as regulatory changes and supply chain efficiencies. [13] According to a labeling trend survey, the label industry is consistently facing data issues, demand label production, label defect, regulatory compliance, label changes, and global standardization issues. [13] Research conducted in the labeling industry is striving to solved industry pain points by applying Lean Six Sigma methodologies to improve productivity, waste, lead times, cost of a product, Define Measure Analyze Implement Control (DMAIC), Value Stream Map, Root Cause Analysis, Pareto Charts, and 5-Why Analysis methodologies. [2] In another research paper related to the industry, a printing process analyze a label manufacturer with quality function deployment, single minute exchange of die, and Pareto Charts methods to improve the quality and efficiency of the overall manufacturing site. In related research, a discrete event simulation model was developed to increase the efficiency of a production process in the newspaper industry by replicating the real-world scenario into a virtual system with 3 replications of potential solutions scenarios with Flexsim software [15].

DISCRETE-EVENT SIMULATION (DES) METHODOLOGY

Discrete-Event Simulation models' purpose is to mimic reality into a virtual scenario with logical processes, state variables, events, databases, and definitions. DES systems are tools for decision-makers to support their efforts in achieving objectives such as evaluation of efficiency, forecast allocation needs, reduction of costs, and improvement of operations. [1] Another literature review describes SIMIO as an "application benefits from more recent object-oriented design and agent modeling. SIMIO is a" multi-modeling" language with agents and a discrete event and continuous language components. SIMIO software provides a visual representation through 3-D animation and graphical representation" Overall, industries have widely adopted SIMIO to highlight the simulation modeling tools. [18]

Multiple studies analyzed the integration of DES model into the research. A study conducted reviews the creation and evaluation of an iterative optimization-based simulation model for different key performance optimizers: average tardiness, earliness cost of the job, and max completion time of the jobs. [3]

An explanatory simulation model research reviewed a SIMIO application in the medical supply chain industry, reviewing the number of patients and inventory control methodologies. All to implement an actual application for the medical supply chain industry and assess the warehouse's performance and flow. [7]

The study conducted in a sterile drug manufacturing examines lead-times and risk reduction assessments of a drug product manufacturing utilizing SIMIO application to implement a sensitivity analysis and optimization process to decrease lead times. [21]

Research reviews an Automotive Supply Chain with simulation modeling. SIMIO application is employed to assess stock levels, percentages of a supplier, on-time deliveries, percentage of special freights, and percentage of delayed orders in the automotive industry. The goal of this model validation analysis is to validate the current scenario [24]

Research assessing a modeling and simulation on inventory management solves inventory levels by optimizing results, reducing cost and resources, and maximizing the utilization of the limited resources by utilizing a simulation model. [25]

An investigation of an Artistic Printing Enterprise reviews the modeling and simulation of inventory management system utilizing ARENA simulation modeling. [4] This research aims to optimize the inventory decision-making and demand forecast for intermittent and uncertain demand in the company.

In related newspaper industry research, a discrete event simulation model (DES) seeks to assess the efficiency of a production process in the newspaper industry by replicating the real-world scenario into a virtual system with three replications of potential solutions scenarios with Flexsim software [15].

The comprehensive analysis conducted in table 2.1 discusses simulations tools with KPIs measure is a powerful tool to analyze a manufacturing setting. Useful simulation applications discovered are SIMIO, ARENA, and Flexsim. This research will consist in implementing a SIMIO model will analyze KPI measure to evaluate the manufacturing of the labeling industry.

Key Performance Indicators are known to measure the organizational performance is critical to an organization's current and future success [4]. It is essential to understand a simulation-based model applies in different areas with different key performance indicators will help improve the cost, efficiency, performance, and optimization of a facility manufacturing.

The literature review results concluded at least one Key performance indicator participates in a manufacturing setting. The revealing KPIs in the literature reviews described in Table 2.1 are throughputs, schedule utilization, inventory measures, and setup times. Table 2.1 describes the tools, methodologies, and research objective in another research. This research will utilize SIMIO simulation models with the objective of measuring KPIs: throughputs, setup time, and schedule utilization.

Table 2.1: Literature Review

	Tools								Methodology						Research Objective																	
Authors	SIMIO	ARENA	Simulation-Generic	Matlab	Visual Basic Application	Flexisim	Entreprise Analysis Model	Other	Lean Six Sigma	Metaheuristic Algorithms	Simulation Modeling	QFD	FMEA	Inventory Control	Throughput	Setup Time	Average Tardiness	Job Earliness	Time in System	Schedule Utilization	Work in Progress	Inventory Measure	Overall Equipment Effectivess	Quality Ratio	On-Time Delivieries	Takt Time	Employee Efficiency	First Pass Yield	Unit/Line Reliability	Lead Times	Cost	Service Level
Onwubolu et al. (2006)					X										X							X										X
Ali (2008)			X								X				X	X			X	X									X			
Wang S. (2010)			X								X			X								X									X	
Chan et al. (2014)								X	X						X										X							X
Tesfaye et al. (2014)		X									X			X	X							X										
Hassam et al. (2014)	X										X			X	X	X					X	X										
Javengi et al. (2015)								X	X				X		X							X										
Joines et al. (2015)	X								X		X			X	X	X	X	X	X	X			X		X					X	X	X
Dehghani et al. (2017)	X			X						X							X	X	X													
Lipiak (2017)			X					X			X									X			X									
Kaganski et al. (2017)							X								X	X				X		X	X	X	X	X	X	X	X			
Zahoor et al. (2017)								X	X											X			X									
Moreira et al. (2018)								X															X								X	
Susanto (2018)								X						X								X									X	
Viera et al. (2018)	X										X				X										X							
Riskadayanti et al. (2019)			X			X					X				X								X									
Geetha et al. (2020)			X								X			X	X					X	X											
Smith et al. (2021)	X								X		X			X	X	X	X			X		X								X	X	
Sprindler et al. (2021)	X										X				X															X		
This thesis	X										X				X	X				X												

CHAPTER 3: EXPERIMENTAL DESIGN

The primary focus of this project is to introduce the research methodology of a discrete-event simulation in a labeling manufacturer. The approach allowed for a deeper understanding of SIMIO modeling and provided a way to understand the actual process flow in a manufacturing process. Figure 4.1 shows the process for 1 order request to be fulfilled.

Figure 2.1: Labeling Manufacturing Process

CASE STUDY DESCRIPTION

This research presents a case study to evaluate the proposed methodology for a capacity enhancement project in a current scenario in the labeling industry. The study involves 48 raw material stores at inventory, potentially creating 403 end products. 48 customers register in company's documentation for 8 months of the dataset. The facility runs by 3-floor workers, 4 flexographic printers, 1 digital printer, 3 rewinders, 1 digital rewinder printer. 1161 order accounts for the length of the data. The orders vary from the size, quantity, and complexity of the purchase request from the customer. The dataset includes Order #, Entry Date, Shipping by date, Press Date, Product ID, Product Description, Footage, Cycle times for Actual Run/Setup, Stock Cost, Machine, Customer Name, and Total Quantity. Figure 4.1 shows the process request for an entity to be fulfill. The order activities to fulfill a request are Ticket (Purchase Request) > Raw Material Selection > Before Wash Setup Time>Process Labels (Processing Station) > After Setup Time>Cutting Rewind Station > Packaging Station > Ship Order.

Table 3.1: Resources and SIMIO Model Interpretation

Resources	Count	SIMIO Model
Raw Materials	48	Materials
Finish Goods	403	Entities
Workers	3	Workers
Flexographic Printers	4	Servers
Digital Printer	1	Server
Rewinders	3	Servers
Digital Rewinder	1	Server
Warehouse Sink	1	Sink
End Product Sink	1	Sink

MODEL

Implementing a SIMIO Discrete Event Simulation approach is to contribute to the labeling industry with continuous improvement, process improvement, and key performance indexes analysis. The model runs in different model assumptions, data (tables/rate tables//work schedules), processes, definitions (state variables, inventory, material elements), and experiments.

In illustration, is a simple, functional input-process-output system. However, the system shown in illustration, shows a more sophisticated system input-process-output system used in this research. The map described below shows gathering data, cleaning the database, conducting Excel/Stat: Fit/Minitab statistical analysis, and implementing input data/model logic/experiments/ and results.

Illustration 1.1: Input-Process-Output System

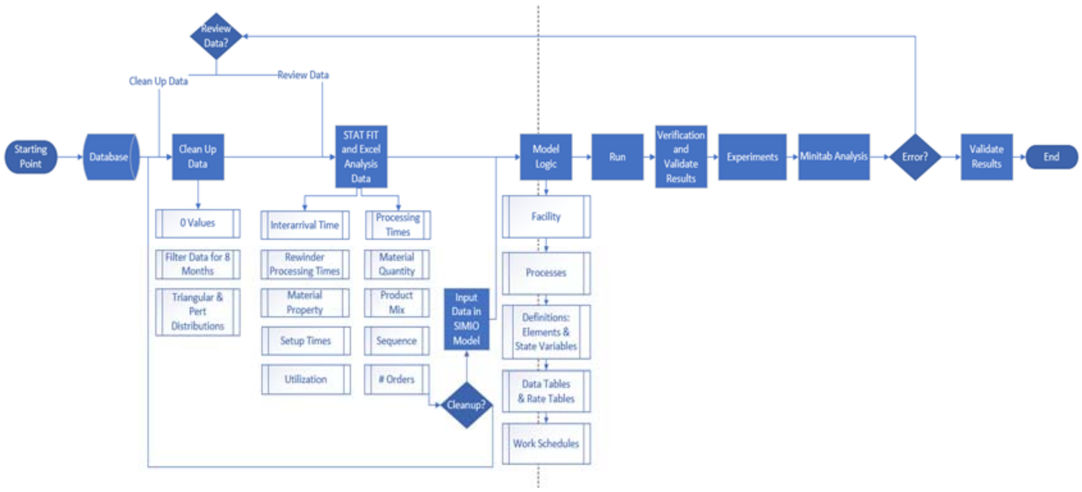


Illustration 2.1: Thesis Process Map

Figure 5.1 below shows the demand distribution with connected data points displaying the y – axis in demand feet square and x- axis in days. More information cannot be display per confidential agreement.

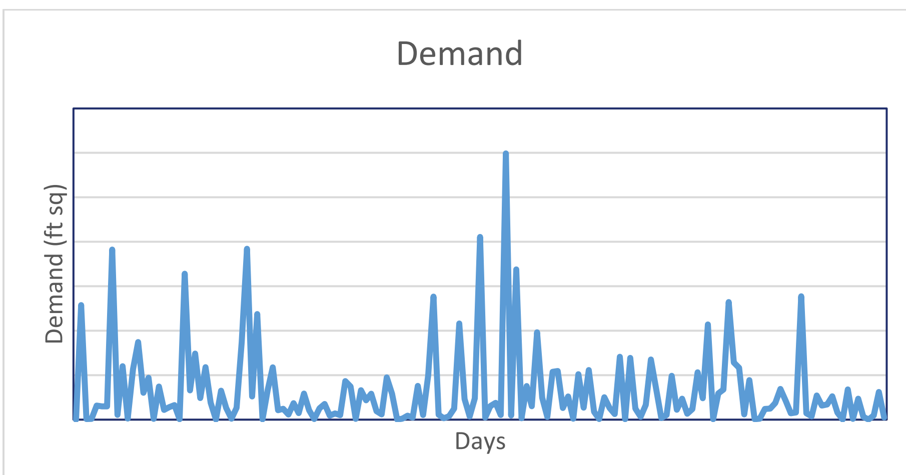


Figure 3.1: Demand for 8 months in manufacturer

DATA ATTRIBUTES

DATA

The simulation data gather from a local labeling manufacturer who wants to understand their process through a simulation model. Statistical analysis was conducted for 8 months of different data tools: tables, data connectors, lookup tables, rate tables, work schedules, changeover matrices, and input parameters. The research only worked with tables, rate tables, and work schedules data. The data analysis consisted in utilizing statistical tools: Microsoft Excel and Stat Fit distribution programs. The input table data for the model organize as in shown table 2: Entity Row, Entity Name, Product Sequence, Raw Material Property, Probability Selection, Interarrival time (minutes), Processing Time (minutes), Material Demand (feet square) Rewind Processing Time (minutes), Washup Time (minutes), and Make Ready Setup (minutes).

Table 4.1: SIMIO Input Parameters

Input Parameters	**Unit of measure**
Interarrival Time	Hours
Flexographic Machine Processing Times	Minutes
Digital Machine Processing Times	Minutes
Rewinder Machine Processing Times	Minutes
Setup time (Before & After)	Minutes
Material Quantity	Feet
Reorder Quantity	Feet
Replenishment Quantity	Feet

MODEL ASSUMPTIONS

The model defines assumptions to approximate the behavior of the system.

Model Assumptions:

- Removed records for orders with negative values in processing times
- Removed order occurrences with 0 minutes in processing times
- Entities (Finish Goods) followed one sequence
- Entities (Finish Goods) followed one raw material
- Entities (Finish Goods) with less than 20 occurrences followed a Triangular distribution
- Entities (Finish Goods) with more than 20 occurrences were analyzed with Stat: Fit Program for distribution identification

- Run model for 8 months due to data accuracy

Assumptions made help to remove misleading values affected the behavior of the system. Entities with one occurrence in the data set will automatically assign the default value. Products follow a distribution are known to have more variability in the process of the labeling manufacturer. In contrast, if an entity follows a distribution, then an entity will require at least 3 occurrences in the data set. All entities with a minimum of three occurrences will follow a Triangular and Pert distribution describing the minimum, mode, and maximum in minutes. Every entity exceeds more than twenty occurrences inputted. to a Stat Fit data analyzer to best fit the data. Stat fit Analyzer utilizes distributions with more than twenty values and no more than one hundred occurrence sets. Distributions run by stat fit will follow Anderson darling test and p-value analysis to confirm distribution accuracy. P-value fits distribution highest to lowest rank percentages and p-value results. Stat Fit program analyzes data by the best-fitted distribution.

The study applies the following formulas to the input parameters:

Interarrival formula

$$Interarrival\ Time = \frac{\sum Sum\ of\ total\ order\ occurrence\ per\ months}{Total\ hours\ available\ in\ a\ month}\ \text{(hours)}$$

Processing Times for Flexographic, Digital, and Rewinder

$$Minimum\ value = \min\ of\ processing\ time\ (value)$$

$$Mode\ value = \frac{\sum Sum\ of\ process\ time\ per\ type\ of\ entity}{Total\ occurrences}$$

$$Maximum\ value = \mathrm{m}aximum(value)$$

$$Triangular\ Distribution = (minimum,\ mode,\ maximum)\ (minutes)$$

SIMIO Table expression parameters 1: Table Worksheet (name of the worksheet table).

Row Name (name of the table). Example: ReferenceTable.ProcessingTime

Setup Times Formula

$$Minimum\ value = \min\ of processing(value) * 20\ \%\ actual\ processing\ time$$

$$Mode\ value = \frac{\sum Sum\ of\ process\ time\ per\ type\ of\ entity}{Total\ occurrences} * 20\%\ acutal\ processing\ time$$

$$Maximum\ value = maximum(value)$$

Triangular $Distribution = (minimum,\ mode,\ maximum)\ (minutes)$

SIMIO Distribution Expression 1: Random. (Distribution Name) Example:

Random.Triangular (minimum, mode, maximum).

Material Quantity:

$$Minimum\ value = \min\ (value)$$

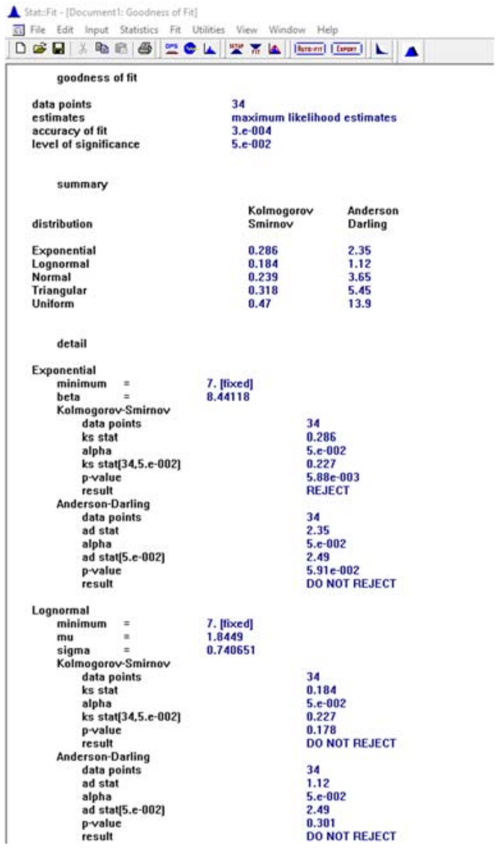
$$Mode\ value = \frac{\sum Sum\ of\ total\ Material\ Demand\ per\ type\ of\ entity}{Total\ occurrences}$$

$$Maximum\ value = maximum(value)$$

$$Pert\ Distribution = (minimum,\ mode,\ maximum)\ (feet)$$

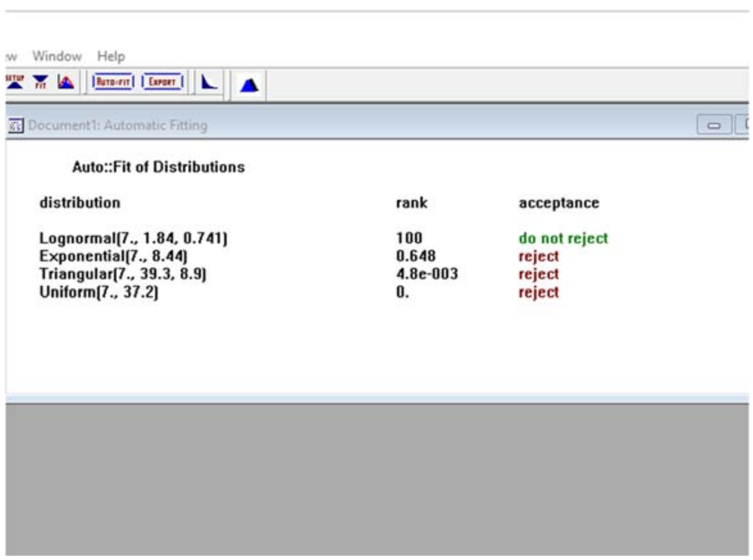
Distribution Expression 1: Random. (Distribution Name) Example: Random.Triangular

(minimum, mode, maximum).



-

Figure 4.1: Stat: Fit statistical analysis



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- Figure 5.1: Stat Fit Analysis Example

SIMIO Model Design

Visual representation is the first impression a stakeholder gets to understand a model representation better. SIMIO's goal is to provide a design facility with visual, logical, mathematical interactions can align to the current linear manufacturing site with a source, server, and sink.

Facility Design

Illustration 3.1 exhibits the final facility design. The final facility design consists of 2 status plots, 2 status pie charts, 8 status labels, 1 warehouse, and 1 facility design. Status plots display all machine number processed and schedule utilizations values per a time interval of days. A status pie chart shows the distribution percentage of number processed and schedule utilization per machine. The following expressions utilize in the status plots and pie charts described below: number processed expression Machine_Name_Server.OutputBuffer.NumberExited and Schedule Utilization expression as Machine_Name_Server.Capacity.ScheduledUtilization.

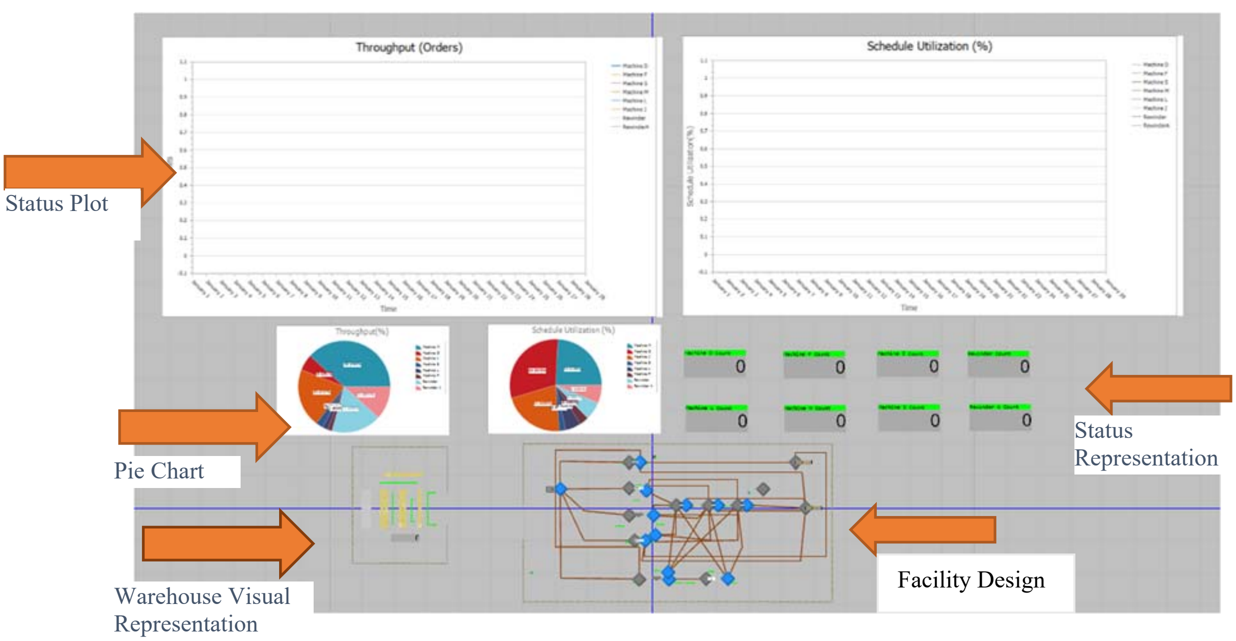


Illustration 3.1: 2-D visual representation of the SIMIO model

SOURCE

An object source "Flexographic" starts with the arrival of a purchase order (ticket) system attached to a product (entity). The arrival mode is attached to a Time-Varying Arrival Rate. Rate tables depend on the rate of occurrence dependent on time. The expression selected at the source table row referencing searches a table of entities, processing times, materials, and sequences. Table row referencing entity is dependent on a probability mix.

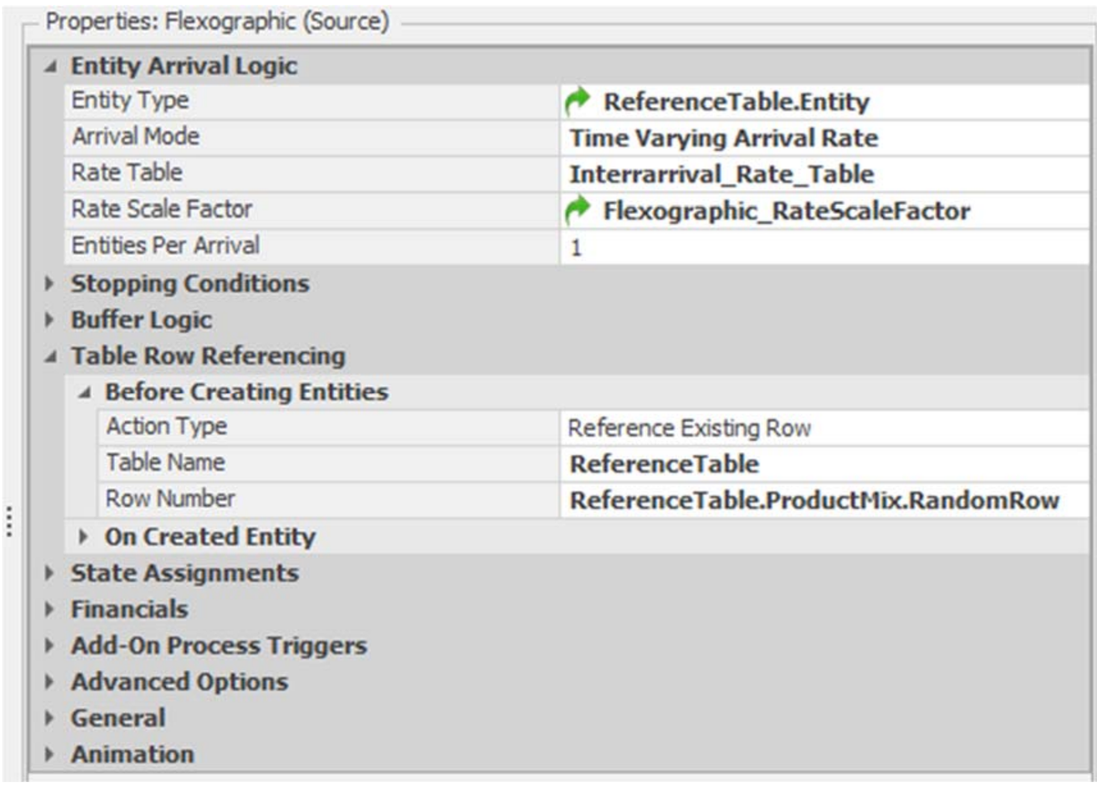


Figure 6.1: Source Object Input Data

SERVER

A server is a critical component for the system to model constraints and capacity, operation performances, and secondary resources. Each entity has a process flow sequence and raw material item add-in to understand the correct route and material an entity should take.

Currently, the facility operates under 6 printing machines servers with the following input data: Schedule, processing Time, add-on process triggers, and advance options (Setup Time). Adjacent to 6 printing machine serves, the facility runs with 3 rewinder servers. Rewinder servers have the following input data: work schedule and processing time.

Each server runs under a capacity type logic of WorkSchedule. Work Schedule represents the work shift of each machine. Each machine runs in an 8 am – 5 pm work schedule. Each entity runs attached to a processing timetable: Reference Table. Processingtime. While referencing the processing times tab, Figure 9.1, under advance options, the model runs the before and after setup times for the model. Setup times occur while the server is preparing and cleaning the machine before a new entity arrives at the server.

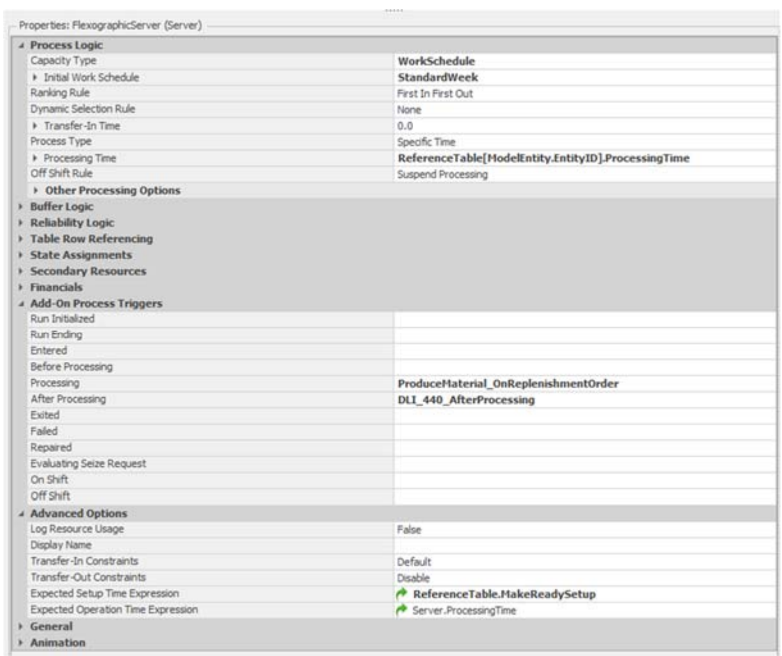


Figure 7.1: Flexographic Server Object Input Data

In addition, four rewinders server objects create the rewind process of making rolls into specific sizes and inspecting quality defects. The model work schedule runs in two different work schedules: Standard Week 8:00 am – 5:00 pm and Work Schedule1 (0 hours tracing off-shift modeling). Rewinder Processing times attach to a ReferenceTable.Rewinder.

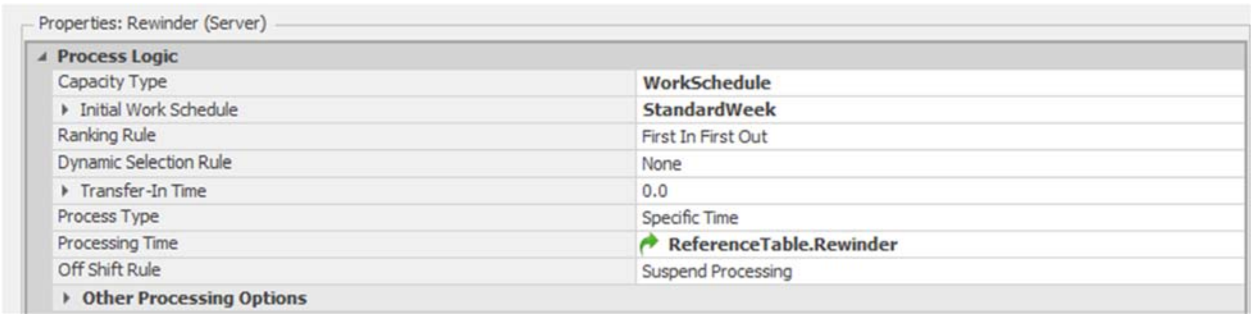


Figure 8.1: Rewinder Server Input Data

While an entity is processing, an expression attached to define the count of entities in each machine server with a state variable. [12] Each machine server has a model logic under states assignments>after each server, the logic is to count every entity exits the system. Figure 12.1 assigns a state variable for each machine to count state variable + 1. Expression state variable + 1 counts the state variable value + 1 every time an entity exits the system. For the duration of the model run, the status count will generate the total count for each machine server.

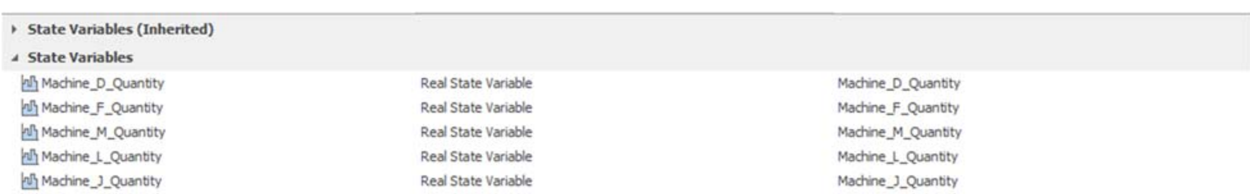


Figure 9.1: Model State Variables

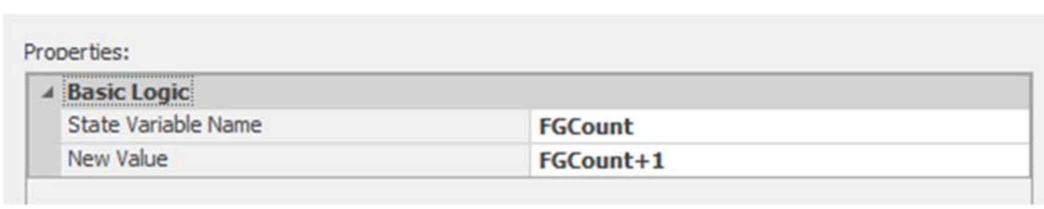


Figure 10.1: Count = State Variable + 1

At the end of each machine server output node, a logic defines the entity destination based on a rewinder server availability. The entity destination path is selected to be in a network only. The two destination paths assign Input Rewinder and Input Rewinder A.

Properties: Output@Machine_F_Server (TransferNode)

Crossing Logic	
Initial Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
Routing Logic	
Outbound Travel Mode	**Network Only**
Outbound Link Preference	Any
Outbound Link Rule	Shortest Path
Entity Destination Type	**Select From List**
Node List Name	**AvailableRewinder**
Selection Goal	**Random**
Selection Condition	
Blocked Destination Rule	Select Available Only
Other Routing Out Options	
Transport Logic	
Ride On Transporter	False

Figure 11.1: Output Destination Path

Along with the after-processing, a process step is to mimic the cleanup wash setup time. Under figure 14.1, a setup time ReferenceTable. Make ReadySetup interpret the before wash setup time. In figure 15.1, a delay step shows each entity's delay for setup time after being processed. The after wash depends on the complexity of the entity.

Advanced Options	
Log Resource Usage	False
Display Name	
Transfer-In Constraints	Default
Transfer-Out Constraints	Disable
Expected Setup Time Expression	**ReferenceTable.MakeReadySetup**
Expected Operation Time Expression	Server.ProcessingTime

Figure 12.1: Before Wash Process Setup Time Expression

Figure 13.1: After Wash Process Setup Time Delay Step

Figure 14.1: Delay Step: Setup Time Process

An element is a model component with specific built-in properties, states, and behaviors. [12]. The model utilizes elements to define the initial quantity of a raw material. The material element quantification is based on the total demand mount of raw materials run by end products. A total of 48 materials are registered and designated to end products.

Figure 15.1: Material Properties

The Rewinder Add–On Process Trigger models a process logic to define the inventory production and consumption of a material, setup time for the before/after-wash process of an entity for all printing machines will produce material. While processing, a Produce/Consume process logic is to replenish or meet material quantity.

The intended use of the before process trigger is to produce and consume material with a decision step. The decision step entails (ReferenceTable.MaterialQTY >= ReferenceTable.InitialQTY), if material quantity is greater than or equal to Initial quantity, actual logic: consume step is added to consume material from the ReferenceTable.Material Property and if false logic: the material is replenished with a production step from a ReferenceTable. MaterialQTY and a consumption step, consume and produce from the Reference. Table. MaterialQTY. The aim is to connect raw materials consumed on the site.

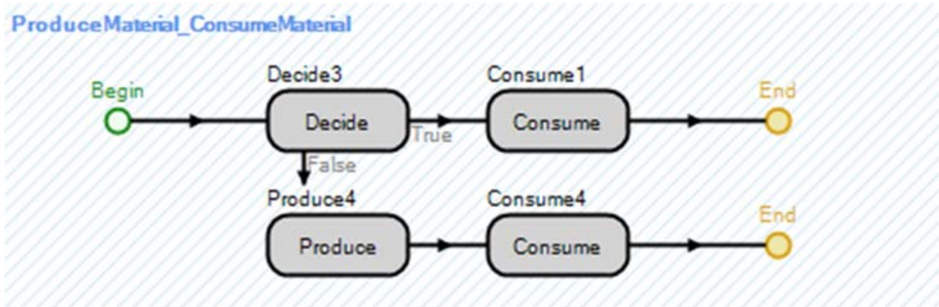


Figure 16.1: Produce and consume step

SINK

All entities start in a source and end in a sink. Sinks are known to destroy entities have fully finished a process. The SIMIO facility has 2 separate sinks: warehouse and end-product sinks. The warehouse sink entities get a process in Machine D. After being processed, the schedule utilization is for Machine D, 16.22% entities to Machine J, 63.1%, end product sink, and 20 % for warehouse sink. Once an entity reaches the end-product and the warehouse sinks, entities will ship customers. The overall logic utilized in this research is to model the current scenario of the label manufacturing system.

CHAPTER 4: RESULTS AND FINDINGS

Results show the importance of utilizing a simulation model in a manufacturer labeling company. The methodologies applied to the simulation will lead to the development of a model development phase diagram, model verification and validation, model visual representations, KPIs results, experiments, and main effect plots.

SIMIO Verification and Validation Final Model

The research conducted in SIMIO describes the verification and validation of research with simulation model development phases, model trace tools, visual representations, results, breakpoints, and experiments. The model defines a simulation model development structure to develop a sophisticated model. Figure 19.1, the simulation model development describes this research's planning, model, and verification/validation phase.

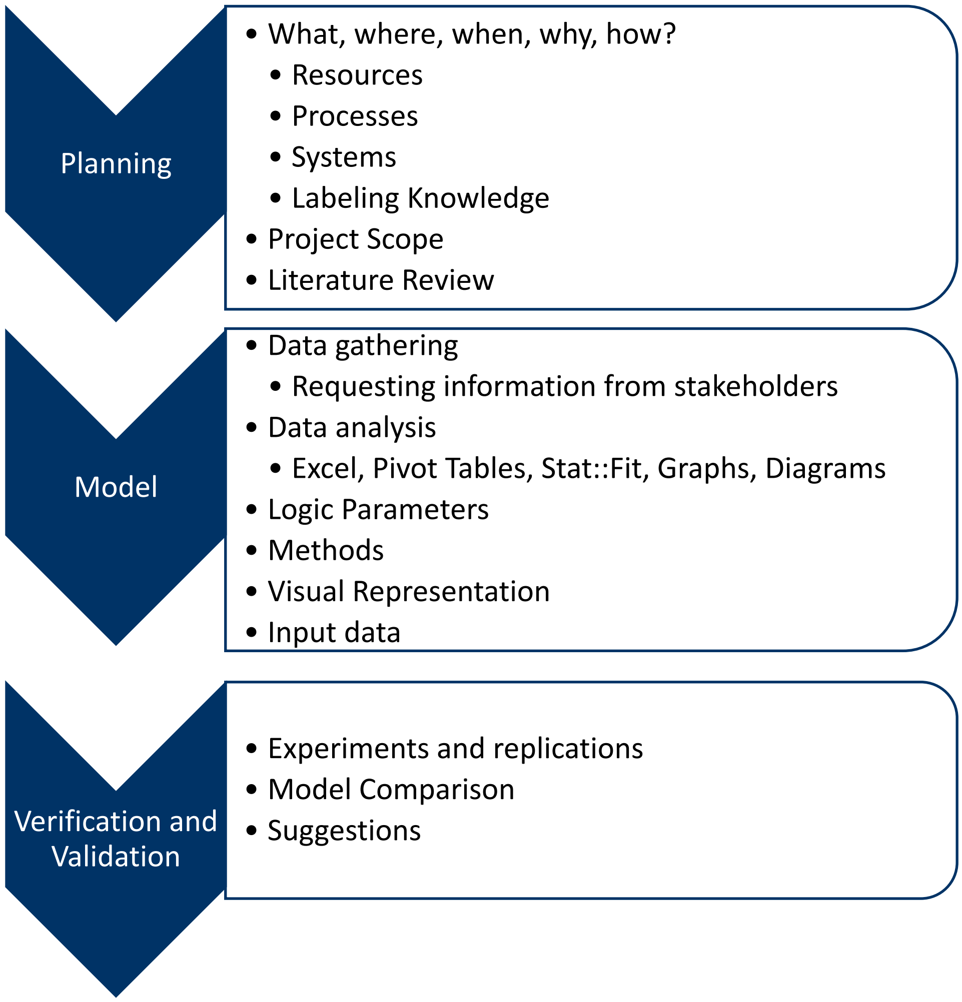


Figure 17.1: Simulations Model Development Phase Implementation

The illustration shows the representation of the labeling manufacturer using SIMIO tools. SIMIO tools displayed below are the manufacturing warehouse's visual representation, manufacturing process representation, status labels, status plots, and status pie charts. The information displayed in labels, plots, and charts shows the system's behavior during the run and during a specific time. Plots and Pie charts displayed the schedule utilization information in probabilities and time. Status labels run with a state variable to count every time an entity enters a server. The overall objective of the plots, charts, and labels is to display run time information of the system.

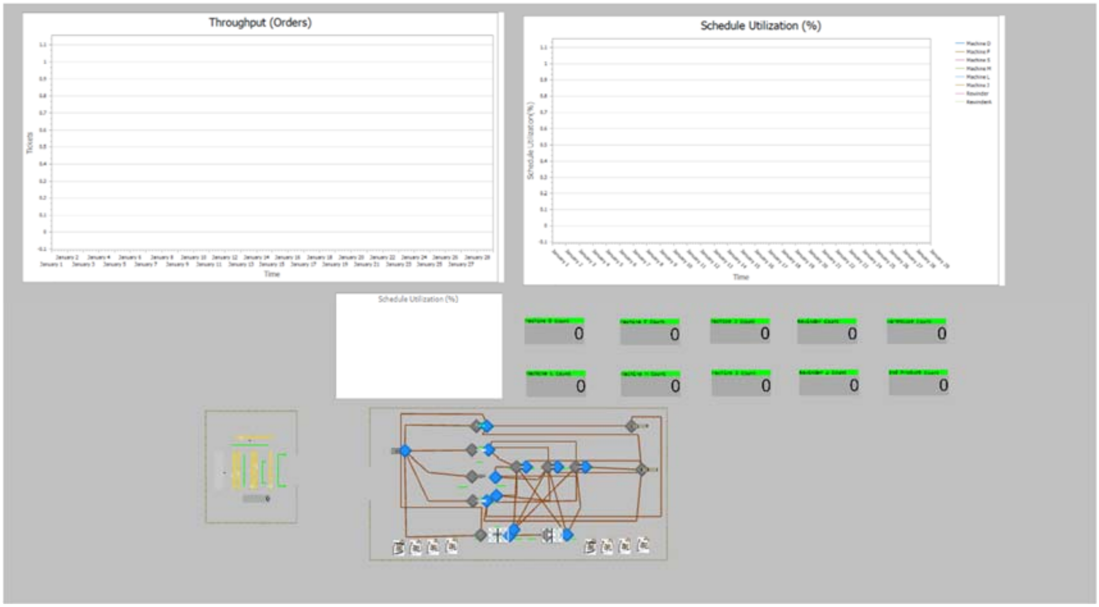


Illustration 4.1: 2-D visual representation of the SIMIO model

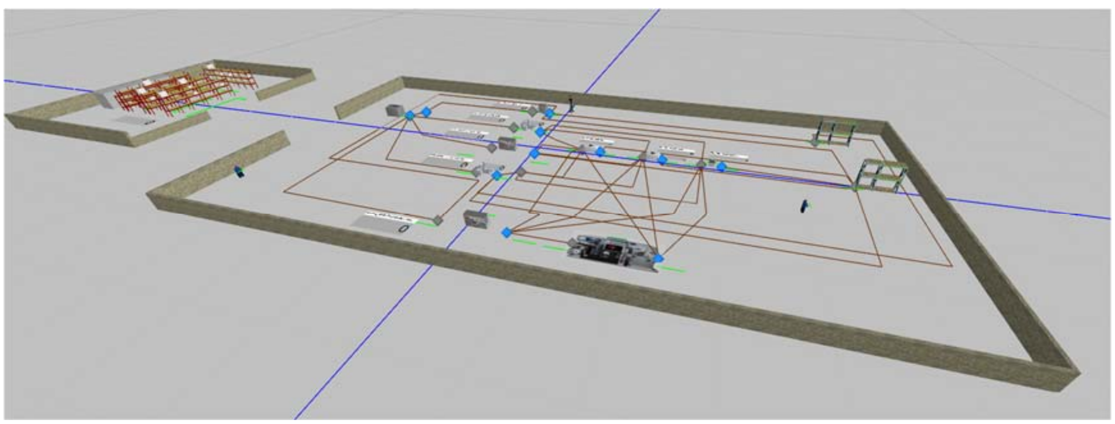


Illustration 5.1: 3-D visual representation of the SIMIO model

The Verification and Validation of a model are essential components for deciding whether a model is running as per logic. An alternative option to verify and validate a model is to utilize the model trace and breakpoints. Model trace is a tool to trace all activities running in the model. Trace modeling identifies each task with the appropriate values of input data. While a breakpoint step is a button to stop the model once an entity or activity arrives at an instance selected. Experiments will assess the overall functionality of the system based on results. Overall, the verification and validation process are an essential component of simulation modeling to measure the accuracy of the project.

EXPERIMENTS

The statistical analysis conducted in the research corresponds to the operation of multiple replications, capacity work schedules, and rate scale factors.

In the conducted research, the objective performs various replications to define the accuracy and proximity of the model. Each machine runs 0, 10, 50, and 100 replications. Model conducting single replications will not validate model results. The importance of replicating the model in various scenarios is to approximate results to actual values.

Model logic for each machine will consist of a standard workweek will run from 8:00 pm to 5:00 pm with the current capacity of 1. The work schedule performs 3 different schedules addressing capacities: Standard Week runs the model with the capacity of 1 resource, Standard Week 2 runs the model with the capacity of 2, and Standard Week 3 runs the model with the capacity of 3.

Scale Factors goal reviews the incremental capacity in a manufacturing site. Every stakeholder knows what the potential of their business is. The SIMIO application will experiment with various scenarios with different scale factors. Scale factors selected in the analysis involve the incremental capacity of 0%, 10%, 50%, and 100% of the actual capacity. The overall objective of utilizing scale factors is to understand the number processed or performance of the company.

The perspective is to experiment in this research model control variables in the system. Control variables in SIMIO Modeling as properties. Properties are a static parameter for an object does not change during the simulation run. [12] In this research, properties assigned to the experiment were work schedules and rate scale factors.

Name	Object Type	Display Name	Category
Properties (Inherited)			
WorkDayExceptions.Properties (Inherited)			
WorkPeriodExceptions.Properties (Inherited)			
Properties			
Quantity	Repeating Group Property	Quantity	Data
Machine_DWorkschedule	Schedule Property	Machine_DWorkschedule	
Machine_MWorkSchedule	Schedule Property	Machine_MWorkSchedule	
Machine_J_WorkSchedule	Schedule Property	Machine_J_WorkSchedule	
Flexographic_RateScaleFactor	Expression Property	Flexographic_RateScaleFactor	
Machine_D_WorkSchedule	Schedule Property	Machine_D_WorkSchedule	
Machine_F_WorkSchedule	Schedule Property	Machine_F_WorkSchedule	
Machine_L_WorkSchedule	Schedule Property	Machine_L_WorkSchedule	
Machine_S_Server_WorkSchedule	Schedule Property	Machine_S_Server_WorkSchedule	

Figure 18.1: Simulation Properties

Replications		Controls	
Completed	Required	Machine_D_WorkSchedule	Flexographic_RateScaleFactor
10 of 10	10	StandardWeek	1
10 of 10	10	StandardWeek2	1
10 of 10	10	StandardWeek3	1
10 of 10	10	StandardWeek	1.1
10 of 10	10	StandardWeek2	1.1
10 of 10	10	StandardWeek3	1.1
10 of 10	10	StandardWeek	1.5
10 of 10	10	StandardWeek2	1.5
10 of 10	10	StandardWeek3	1.5
10 of 10	10	StandardWeek	2
10 of 10	10	StandardWeek2	2
10 of 10	10	StandardWeek3	2
50 of 50	50	StandardWeek	1
50 of 50	50	StandardWeek2	1
50 of 50	50	StandardWeek3	1
50 of 50	50	StandardWeek	1.1
50 of 50	50	StandardWeek2	1.1
50 of 50	50	StandardWeek3	1.1
50 of 50	50	StandardWeek	1.5
50 of 50	50	StandardWeek2	1.5
50 of 50	50	StandardWeek3	1.5
50 of 50	50	StandardWeek	2
50 of 50	50	StandardWeek2	2
50 of 50	50	StandardWeek3	2
100 of 100	100	StandardWeek	1
100 of 100	100	StandardWeek2	1

Figure 19.1: SIMIO Experiments with replications

Figure 22.1 displays the experiment with a standard week 8:00am – 5:00pm schedule and different scale factors attached to the system's source. Scale factors selected in the experiment incremented the factor by 1 with the current capacity of 1 resource. Adding a rating factor will simulate the ability of the manufacturing site to increment the capacity based on the current scenario. The goal is to increment the rate factor by 1 to see the overall number processed and schedule utilization measure of the label manufacturer.

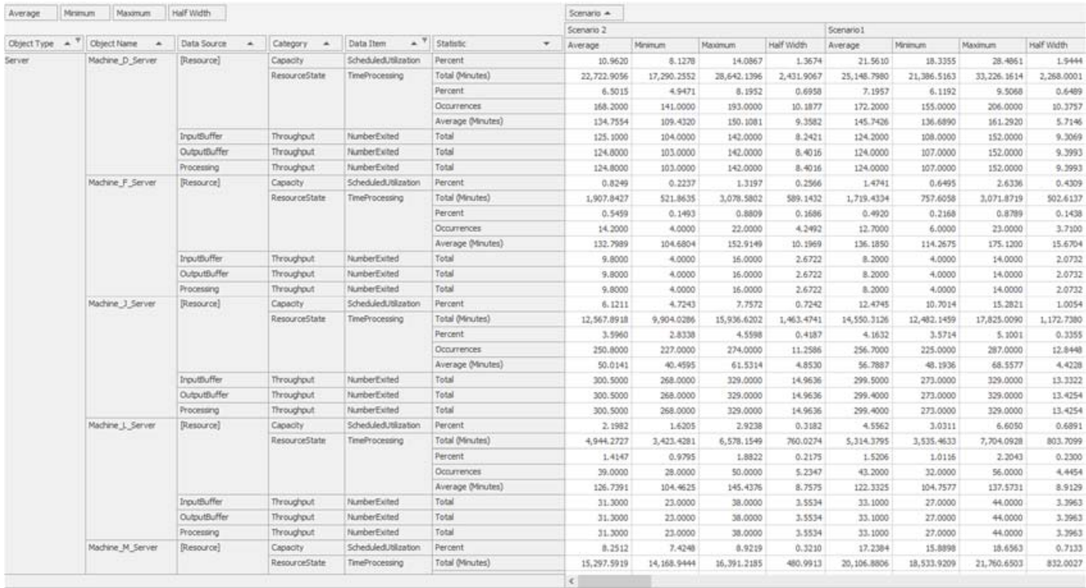
Replications		Controls	
Completed	Required	Machine_D_WorkSchedule	Flexographic_RateScaleFactor
20 of 20	20	StandardWeek	1
20 of 20	20	StandardWeek	2
20 of 20	20	StandardWeek	3
20 of 20	20	StandardWeek	4
20 of 20	20	StandardWeek	5
20 of 20	20	StandardWeek	6
20 of 20	20	StandardWeek	8
20 of 20	20	StandardWeek	9
20 of 20	20	StandardWeek	10

Figure 20.1: SIMIO Experiments with 20 Replications

Figure 24.1 & 25.1, SIMIO model has the capacity to give instant results along with replicated results.

Data Item	Statistic	Average Total
ScheduledUtilization	Percent	8.0754
NumberExited	Total	98.0000
NumberExited	Total	98.0000
NumberExited	Total	98.0000
ScheduledUtilization	Percent	5.0304
NumberExited	Total	66.0000
NumberExited	Total	66.0000
NumberExited	Total	66.0000
ScheduledUtilization	Percent	2.0732
NumberExited	Total	14.0000
NumberExited	Total	14.0000
NumberExited	Total	14.0000
ScheduledUtilization	Percent	21.2186
NumberExited	Total	200.0000
NumberExited	Total	200.0000
NumberExited	Total	200.0000
ScheduledUtilization	Percent	6.6128
NumberExited	Total	13.0000
NumberExited	Total	13.0000
NumberExited	Total	13.0000
ScheduledUtilization	Percent	23.4137
NumberExited	Total	122.0000
NumberExited	Total	122.0000
NumberExited	Total	122.0000
ScheduledUtilization	Percent	2.3011
NumberExited	Total	3.0000
NumberExited	Total	3.0000
NumberExited	Total	3.0000
ScheduledUtilization	Percent	36.0883
NumberExited	Total	48.0000
NumberExited	Total	48.0000
NumberExited	Total	48.0000

Figure 21.1: Model Results without replications



Object Type	Object Name	Data Source	Category	Data Item	Statistic	Scenario 2 Average	Scenario 2 Minimum	Scenario 2 Maximum	Scenario 2 Half Width	Scenario1 Average	Scenario1 Minimum	Scenario1 Maximum	Scenario1 Half Width
Server	Machine_D_Server	[Resource]	Capacity	ScheduledUtilization	Percent	10.9620	8.1278	14.0867	1.3674	21.5610	18.3355	28.4861	1.9444
			ResourceState	TimeProcessing	Total (Minutes)	22,722.9056	17,290.2552	28,642.1396	2,431.9067	25,148.7980	21,386.5163	33,226.1614	2,268.0001
					Percent	6.5015	4.9471	8.1952	0.6958	7.1957	6.1192	9.5068	0.6489
					Occurrences	168.2000	141.0000	193.0000	10.1877	172.2000	155.0000	206.0000	10.3757
					Average (Minutes)	134.7554	109.4320	150.1081	9.3582	145.7426	136.6890	161.2920	5.7146
		InputBuffer	Throughput	NumberExited	Total	125.1000	104.0000	142.0000	8.2421	124.2000	108.0000	152.0000	9.3069
		OutputBuffer	Throughput	NumberExited	Total	124.8000	103.0000	142.0000	8.4016	124.0000	107.0000	152.0000	9.3993
		Processing	Throughput	NumberExited	Total	124.8000	103.0000	142.0000	8.4016	124.0000	107.0000	152.0000	9.3993
	Machine_F_Server	[Resource]	Capacity	ScheduledUtilization	Percent	0.8249	0.2237	1.3197	0.2566	1.4741	0.6495	2.6336	0.4309
			ResourceState	TimeProcessing	Total (Minutes)	1,907.8427	521.8635	3,078.5802	589.1432	1,719.4334	757.6058	3,071.8719	502.6137
					Percent	0.5459	0.1493	0.8809	0.1686	0.4920	0.2168	0.8789	0.1438
					Occurrences	14.2000	4.0000	22.0000	4.2492	12.7000	6.0000	23.0000	3.7100
					Average (Minutes)	132.7989	104.6804	152.9149	10.1969	136.1850	114.2675	175.1200	15.6704
		InputBuffer	Throughput	NumberExited	Total	9.8000	4.0000	16.0000	2.6722	8.2000	4.0000	14.0000	2.0732
		OutputBuffer	Throughput	NumberExited	Total	9.8000	4.0000	16.0000	2.6722	8.2000	4.0000	14.0000	2.0732
		Processing	Throughput	NumberExited	Total	9.8000	4.0000	16.0000	2.6722	8.2000	4.0000	14.0000	2.0732
	Machine_J_Server	[Resource]	Capacity	ScheduledUtilization	Percent	6.1211	4.7243	7.7572	0.7242	12.4745	10.7014	15.2821	1.0054
			ResourceState	TimeProcessing	Total (Minutes)	12,567.8918	9,904.0286	15,936.6202	1,463.4741	14,550.3126	12,482.1459	17,825.0090	1,172.7380
					Percent	3.5960	2.8338	4.5598	0.4187	4.1632	3.5714	5.1001	0.3355
					Occurrences	250.8000	227.0000	274.0000	11.2586	256.7000	225.0000	287.0000	12.8448
					Average (Minutes)	50.0141	40.4595	61.5314	4.8530	56.7887	48.1936	68.5577	4.4228
		InputBuffer	Throughput	NumberExited	Total	300.5000	268.0000	329.0000	14.9636	299.5000	273.0000	329.0000	13.3322
		OutputBuffer	Throughput	NumberExited	Total	300.5000	268.0000	329.0000	14.9636	299.4000	273.0000	329.0000	13.4254
		Processing	Throughput	NumberExited	Total	300.5000	268.0000	329.0000	14.9636	299.4000	273.0000	329.0000	13.4254
	Machine_L_Server	[Resource]	Capacity	ScheduledUtilization	Percent	2.1982	1.6205	2.9238	0.3182	4.5562	3.0311	6.6050	0.6891
			ResourceState	TimeProcessing	Total (Minutes)	4,944.2727	3,423.4281	6,578.1549	760.0274	5,314.3795	3,535.4633	7,704.0928	803.7099
					Percent	1.4147	0.9795	1.8822	0.2175	1.5206	1.0116	2.2043	0.2300
					Occurrences	39.0000	28.0000	50.0000	5.2347	43.2000	32.0000	56.0000	4.4454
					Average (Minutes)	126.7391	104.4625	145.4376	8.7575	122.3325	104.7577	137.5731	8.9129
		InputBuffer	Throughput	NumberExited	Total	31.3000	23.0000	38.0000	3.5534	33.1000	27.0000	44.0000	3.3963
		OutputBuffer	Throughput	NumberExited	Total	31.3000	23.0000	38.0000	3.5534	33.1000	27.0000	44.0000	3.3963
		Processing	Throughput	NumberExited	Total	31.3000	23.0000	38.0000	3.5534	33.1000	27.0000	44.0000	3.3963
	Machine_M_Server	[Resource]	Capacity	ScheduledUtilization	Percent	8.2512	7.4248	8.9219	0.3210	17.2384	15.8898	18.6563	0.7133
			ResourceState	TimeProcessing	Total (Minutes)	15,297.5919	14,168.9444	16,391.2185	480.9913	20,106.8806	18,533.9209	21,760.6503	832.0027

Figure 22.1: Model Results with replications

SIMIO RESULTS

The visual representation is part of the Verification and Validation of the model. KPIs are the performance measures to understand the effectiveness of a facility. KPIs utilize in this research are the total orders number processed and machines schedule utilization. Tables 6.1, 7.1, 8.1, discusses the current number processed and schedule utilization. In addition, the model replicates the current results by 10, 50, and 100 replications to approximate values to the current number processed. Results show Machine D, Machine M, and Machine J are machines with the most orders processed and utilized. Machine F, Machine L, Machine S, Rewinder, and Rewinder A are machines with the lowest number of orders processed and utilized.

Table 6.1: Sinks Number processed per machine

	Current Number processed (units)	**Model NumberProcessed (units) - 10 Replications**	**Model NumberProcessed (units)- 50 Replications**	**Model NumberProcessed (units)- 100 Replications**
Warehouse NumberProcessed	1161	27.6	28.98	29.25
End Product NumberProcessed		1050.3	1056.26	1056.37

Table 7.1: Number processed per machine with replications

	Current Number processed (Units)	Model Number Processed (Units)- 10 Replications	Model Number Processed (Units)- 50 Replications	Model Number Processed (Units)- 100 Replications
Machine_D_NumberProcessed	**133**	**122.9**	**124.08**	**123.34**
Machine_M_NumberProcessed	**611**	**580.9**	**577.72**	**578.43**
Machine_F_NumberProcessed	11	9	10.5	10.65
Machine_J_NumberProcessed	**318**	**317.8**	**317.44**	**315.9**
Machine_L_NumberProcessed	39	30.1	31.94	32.43
Machine_S_NumberProcessed	49	49.7	49.86	50
Rewinder_NumberProcessed	Not Available	206.4	215.6	215.3
RewinderA_NumberProcessed	Not Available	225.7	221.28	220.47

Schedule utilization is calculating the total run time of each machine over the 8 months data set.

$$SU\ per\ machine = \frac{\sum Total\ processing\ time\ per\ machine}{Total\ minutes\ available\ per\ month}$$

Table 8.1: Schedule Utilization results for machines

	Current Utilization (%)	Model Schedule Utilization- 10 Replications (%)	Model Schedule Utilization- 50 Replications (%)	Model Schedule Utilization- 100 Replications (%)
Machine_D_SU	**28.8**	**29.316**	**29.4926**	**29.5848**
Machine_M_SU	**16.6**	**20.6292**	**20.521**	**20.5518**
Machine_F_SU	2.9	2.31444	2.77143	2.84258
Machine_J_SU	**16.5**	**19.2431**	**19.3182**	**19.466**
Machine_L_SU	7.6	5.66509	6.11855	6.09711
Machine_S_SU	2.2	1.96777	2.04709	2.09226
Rewinder_SU	Not available	5.36844	5.79938	5.85909
RewinderA_SU	Not available	5.96857	6.05069	6.02673

Machine D, Machine J, Machine M are high run machine due to time utilize. Machine F, Machine L, Machine S, Rewinder, and Rewinder A are low runner machines has low demand and low time utilize. Machine D is known to be the machine utilized the most due to high utilization value.

MAIN EFFECT PLOT DIAGRAMS

The main effect graphical plot represents and compares the changes in the means to identify the categorical variable influences the response [8].

The diagrams displayed below interpret the standard week machines schedule utilization, scale factors for machines schedule utilization, scale factors for machines Number processed, and scale factors for exited Number processed.

Rate Scale Factor is the factor used to scale the arrival rate values. Rate scale factors diagram address below describes the relationship between Work Schedule and the increment of the rate factor Horizontal lines shown in main effect plots describes the overall mean of the data analyzed.

MAIN EFFECT PLOT: STANDARD WEEK MACHINES SCHEDULE UTILIZATION

Figures 26.1 – 33.1, displays the main effect plots for Machine D, Machine M, Machine F, Machine J, Machine L, Machine S, Rewinder, and Rewinder A further down the analysis of the Schedule Utilization. The Y-axis represents the schedule utilization in percentage (%), and X – the axis displays the capacity per machine in standard weeks. Data employed in the main effect plots are deemed from the experiments' results. The objective is to minimize the schedule utilization of each machine by utilizing standard work week, standard week 2, and standard week 3. The main effect plot averages the total occurrences per Standard week, standard week 2, and standard week 3. Each machine averages 12 scenarios for each schedule. The value of each standard week corresponds to the following formula:

Standard Week Capacity (StandardWeek, StandardWeek 2, StandardWeek 3) = Sum of values per occurrence / Sum of occurrences.

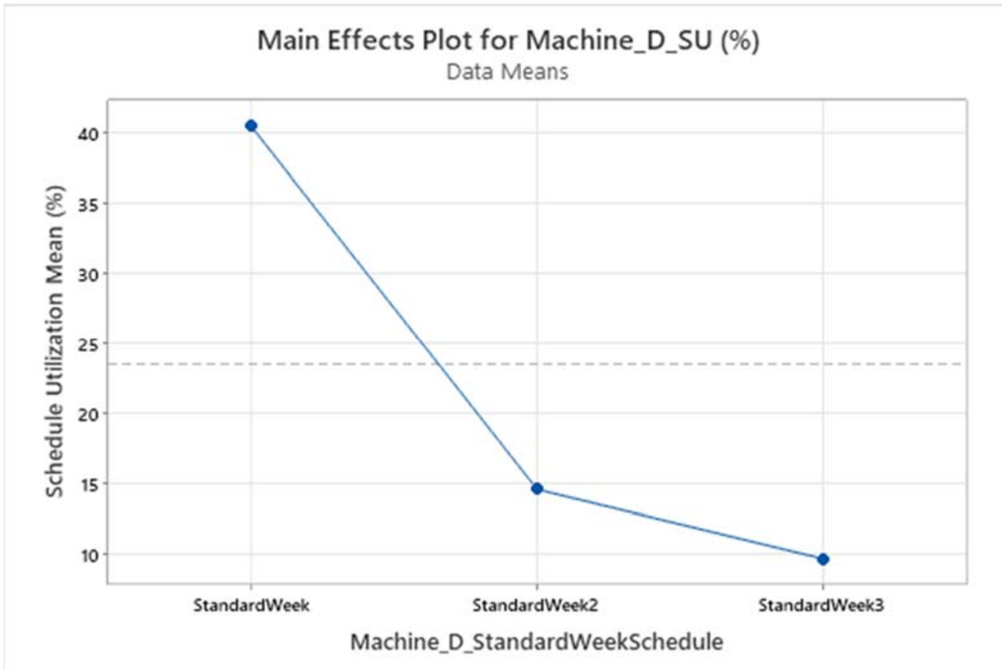


Figure 23.1: Main Effect Plot for Machine D Schedule Utilization (%) Graph

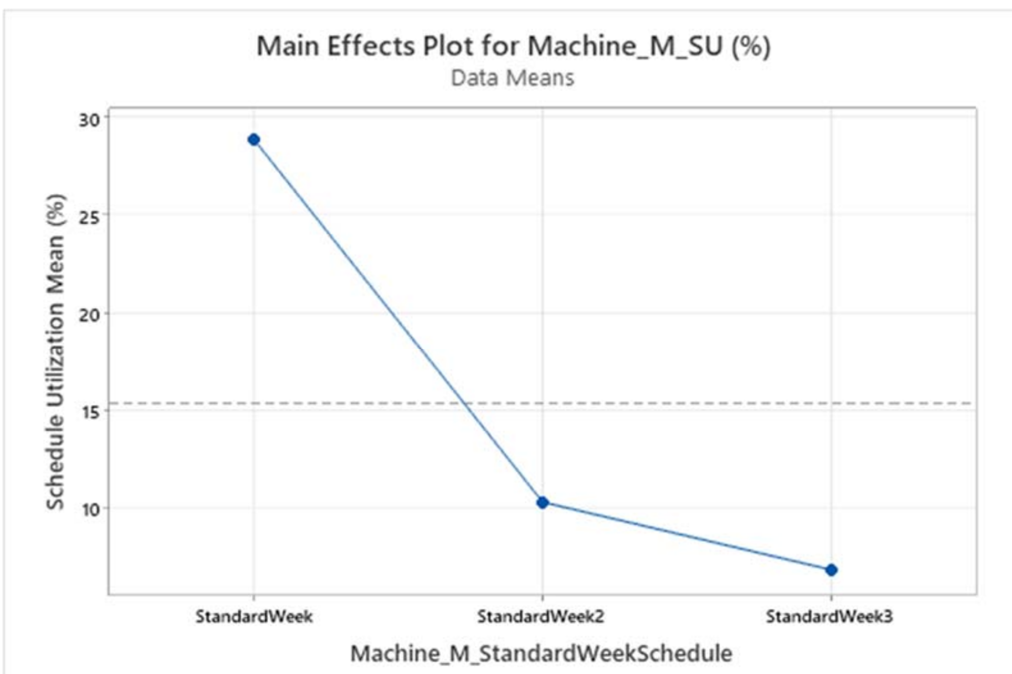


Figure 24.1: Main Effect Plot for Machine M Schedule Utilization (%) Graph

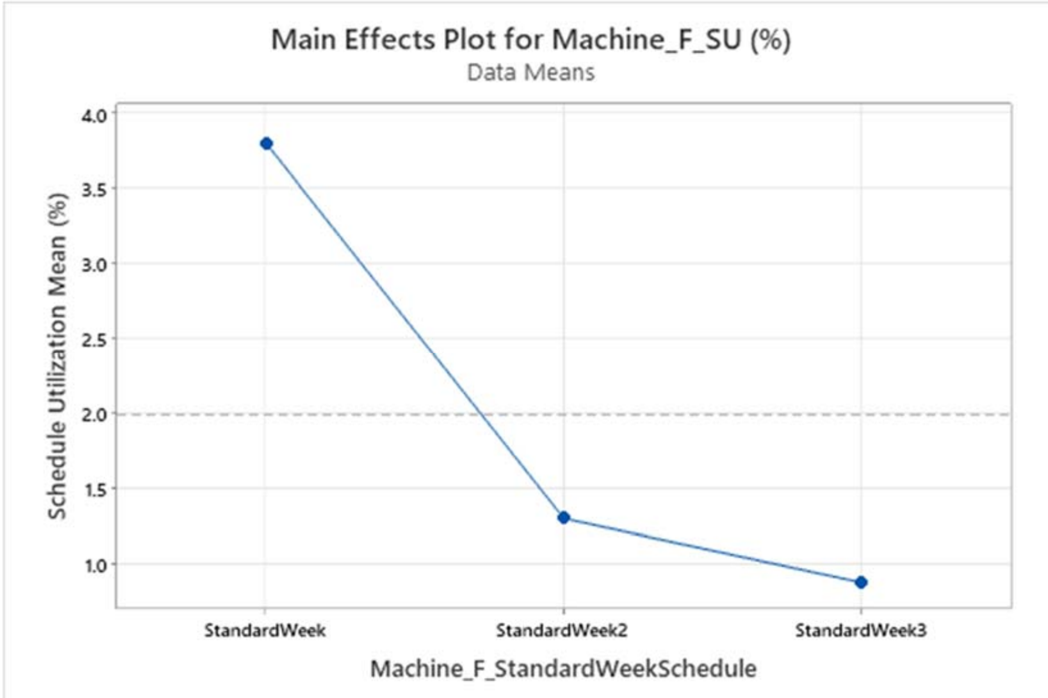


Figure 25.1: Main Effect Plot for Machine F Schedule Utilization (%) Graph

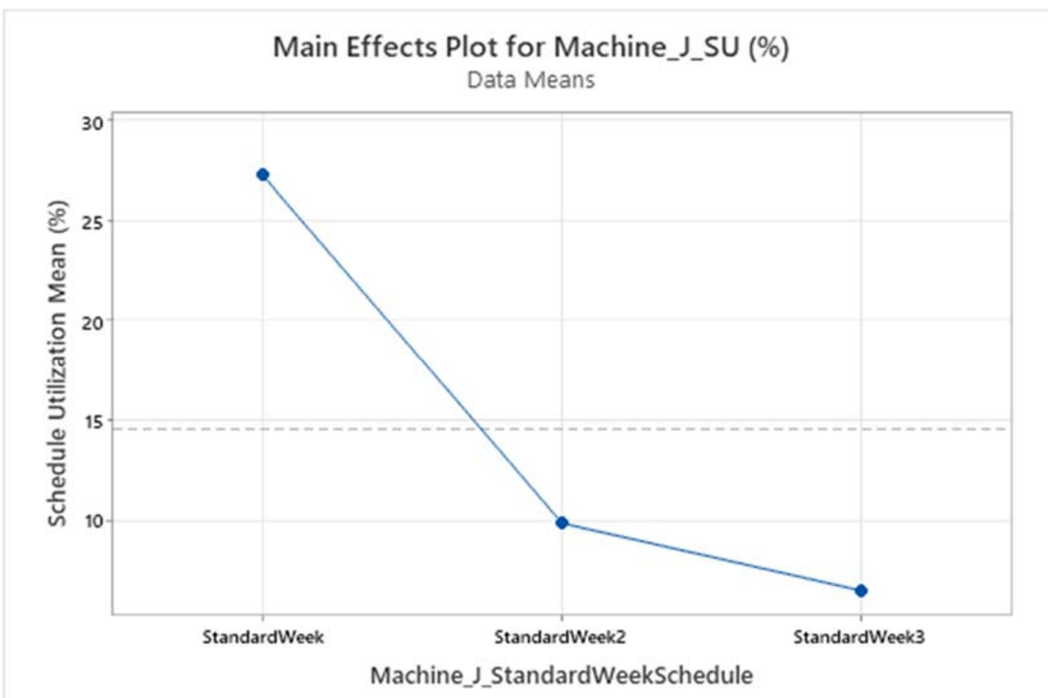


Figure 26.1: Main Effect Plot for Machine J Schedule Utilization (%) Graph

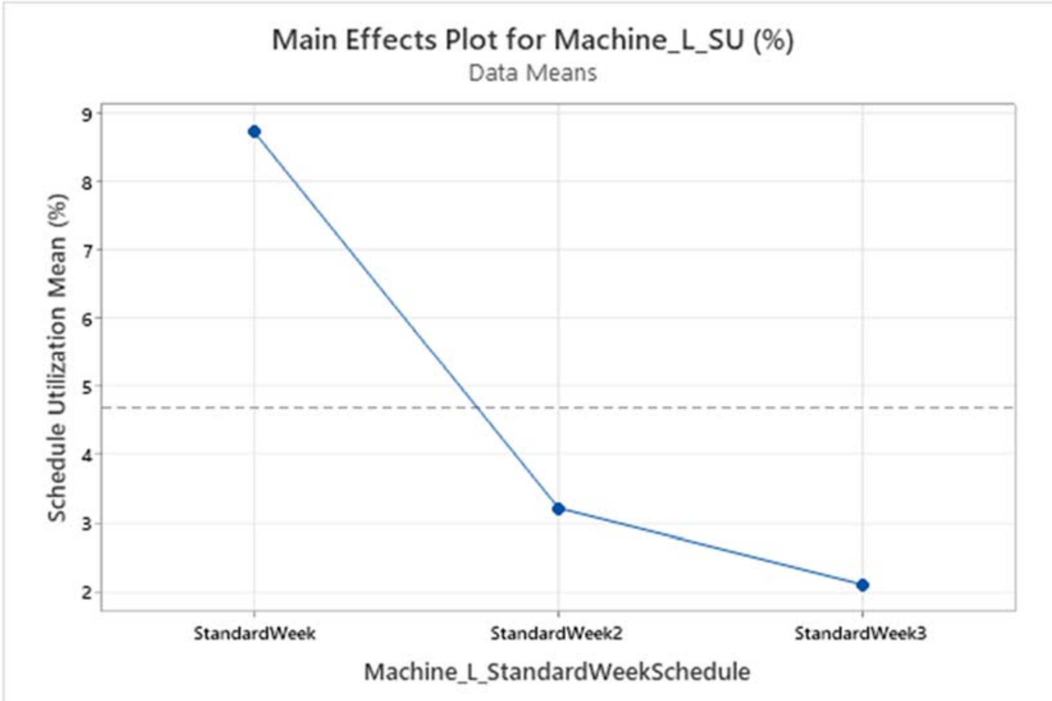


Figure 27.1: Main Effect Plot for Machine L Schedule Utilization (%) Graph

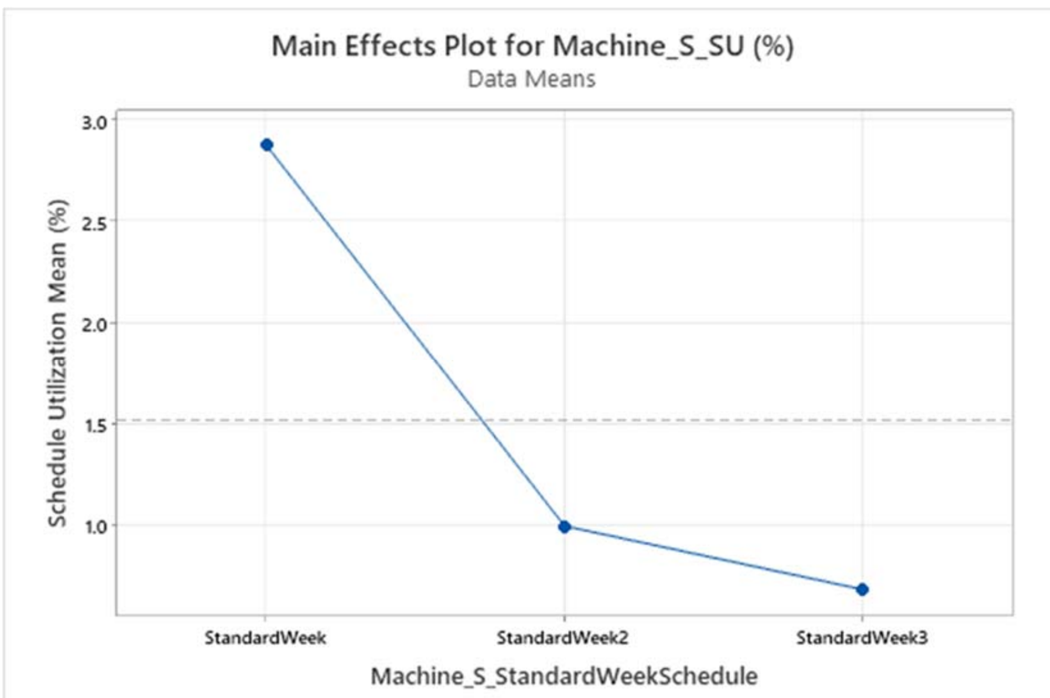


Figure 28.1: Main Effect Plot for Machine S Schedule Utilization (%) Graph

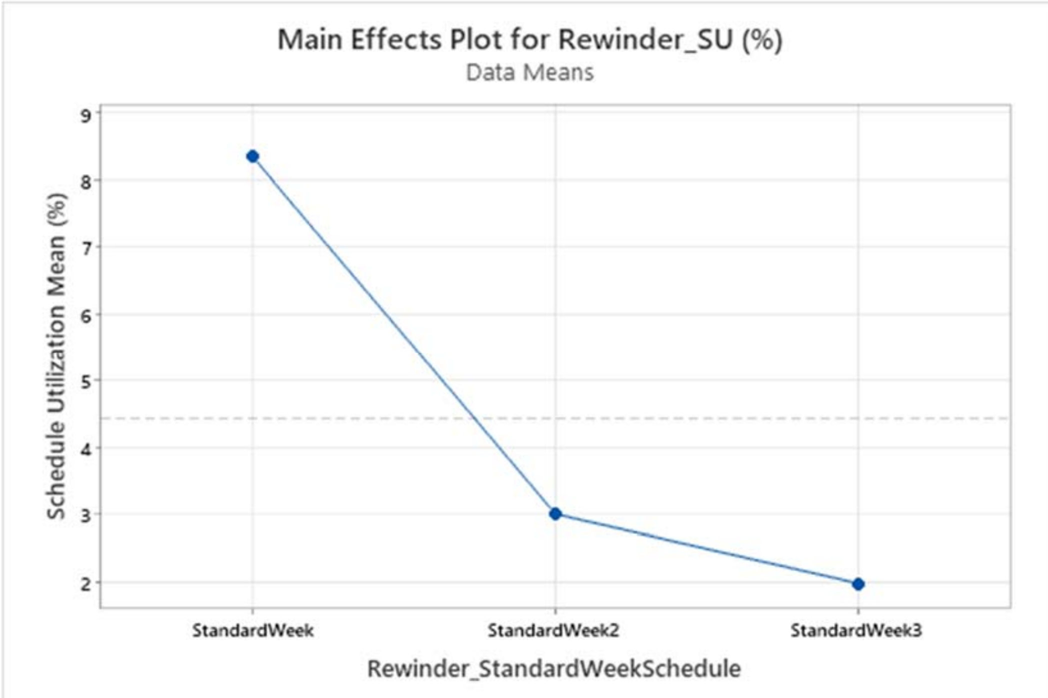


Figure 29.1: Main Effect Plot for Rewinder Schedule Utilization (%) Graph

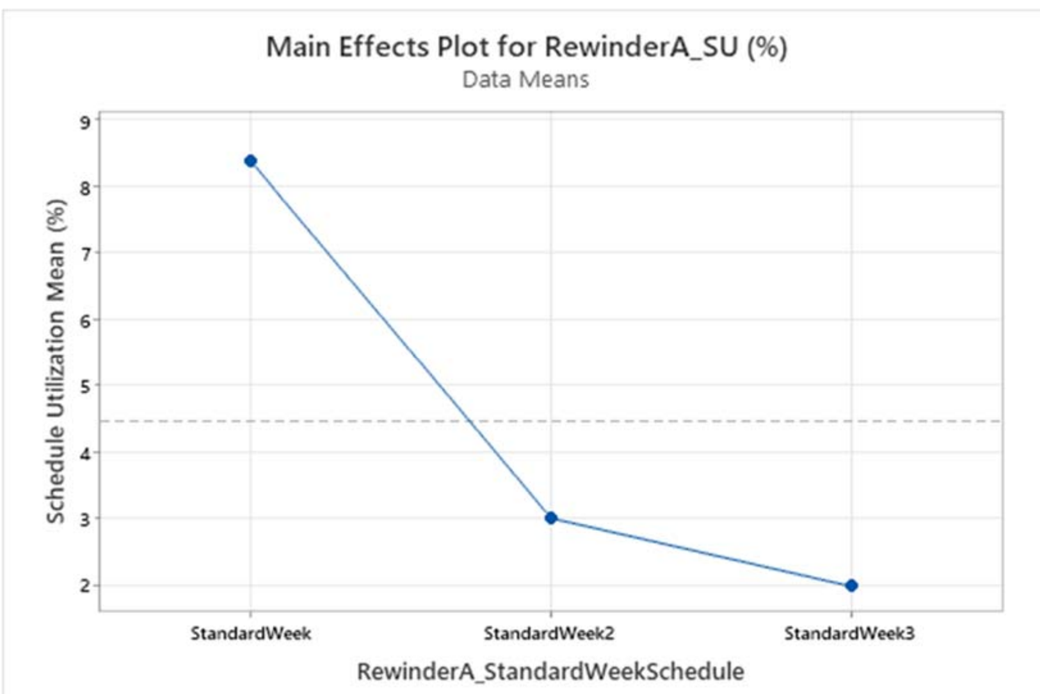


Figure 30.1: Main Effect Plot for Rewinder A Schedule Utilization (%) Graph

MAIN EFFECT PLOT: SCALE FACTORS FOR SCHEDULE UTILIZATION

The purpose of applying a rate scale factor is to the research is to analyze the behavior of a system in different circumstance of growth in the current schedule utilization scenario. The x-axis describes the incrementation rate factor mean values and y-axis is the average of orders requested during the run of the simulation. The main effect plot measures the potential growth of the company with a scale factor of 1.0, 1.1, 1.5, and 2.0. Main Effect Plot for Machines Schedule Utilization with Scale factors calculated as follows:

Scale Factor (1.0, 1.1,1.5,2.0) = Sum of values per occurrences / sum of occurrences.

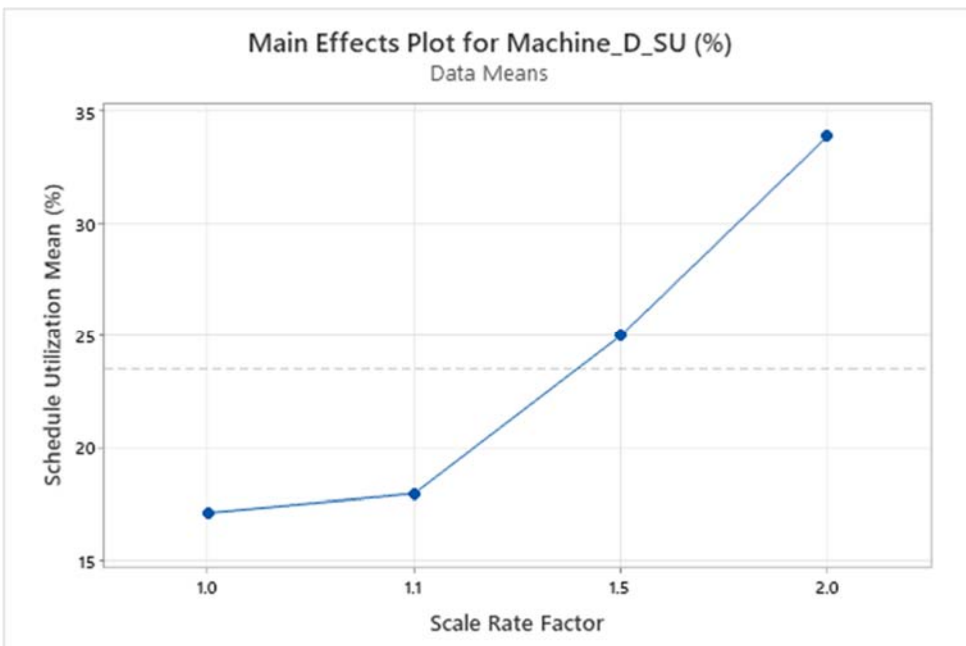


Figure 31.1: Main Effect Plot for Machine D Schedule Utilization (%) with Scale Factors

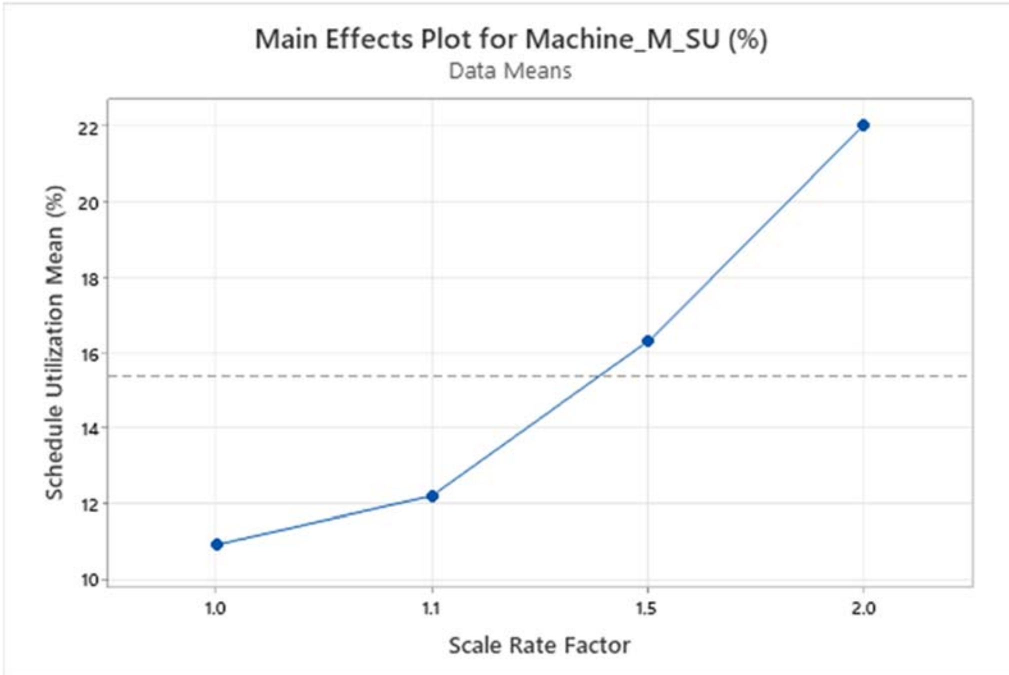


Figure 32.1: Main Effect Plot for Machine M Schedule Utilization (%) with Scale Factors

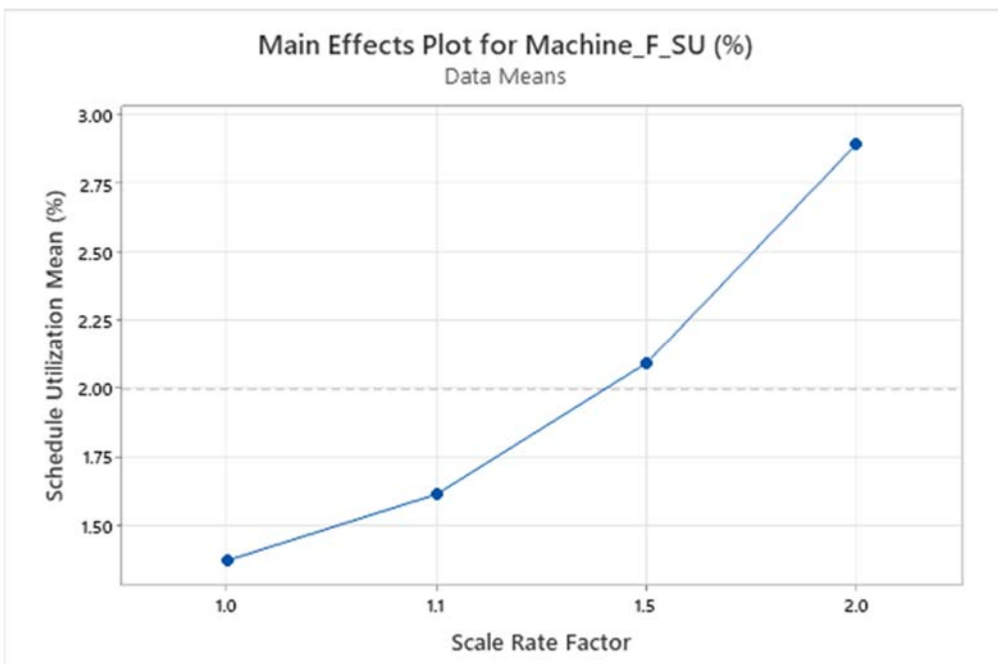


Figure 33.1: Main Effect Plot for Machine F Schedule Utilization (%) with Scale Factors

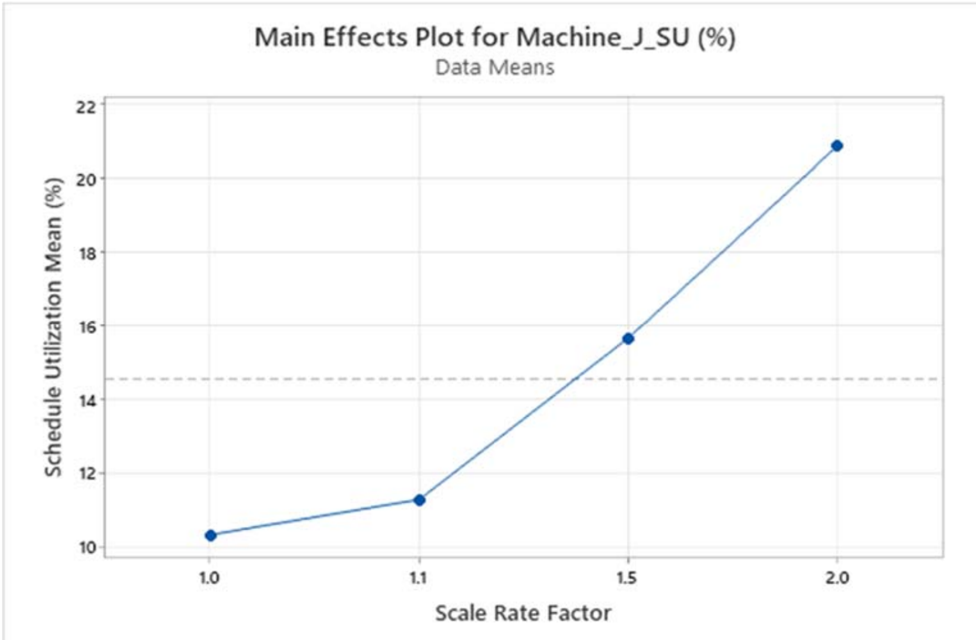


Figure 34.1: Main Effect Plot for Machine J Schedule Utilization (%) with Scale Factors

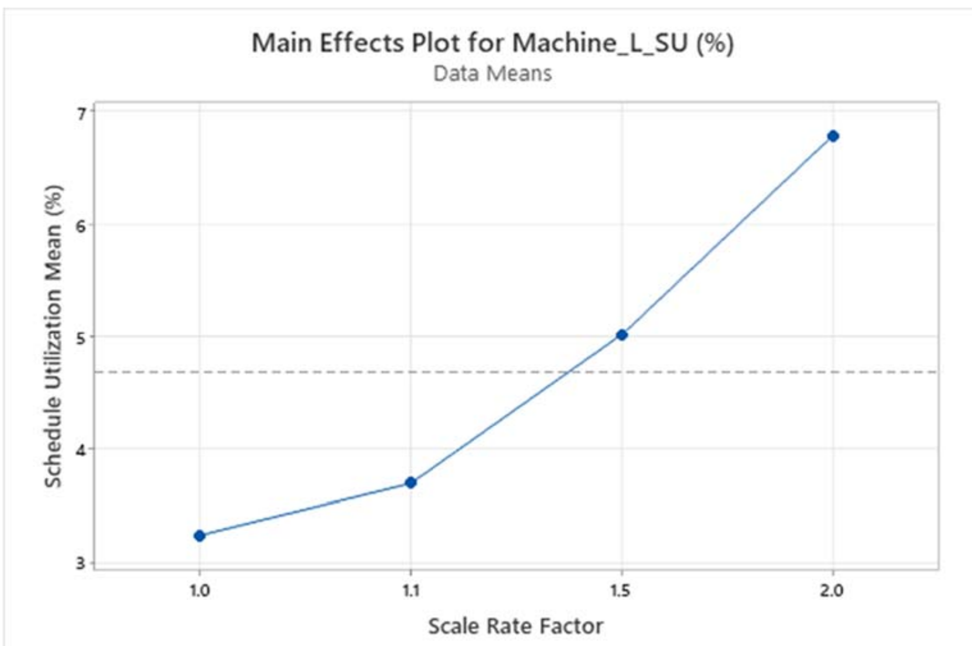


Figure 35.1: Main Effect Plot for Machine L Schedule Utilization (%) with Scale Factors

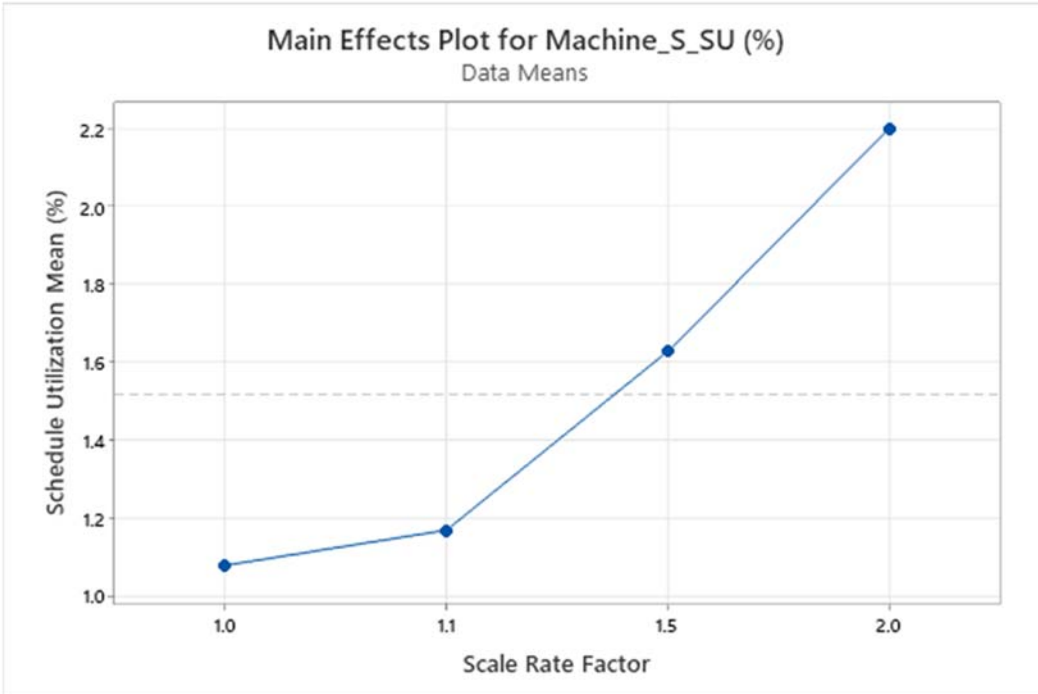


Figure 36.1: Main Effect Plot for Machine S Schedule Utilization (%) with Scale Factors

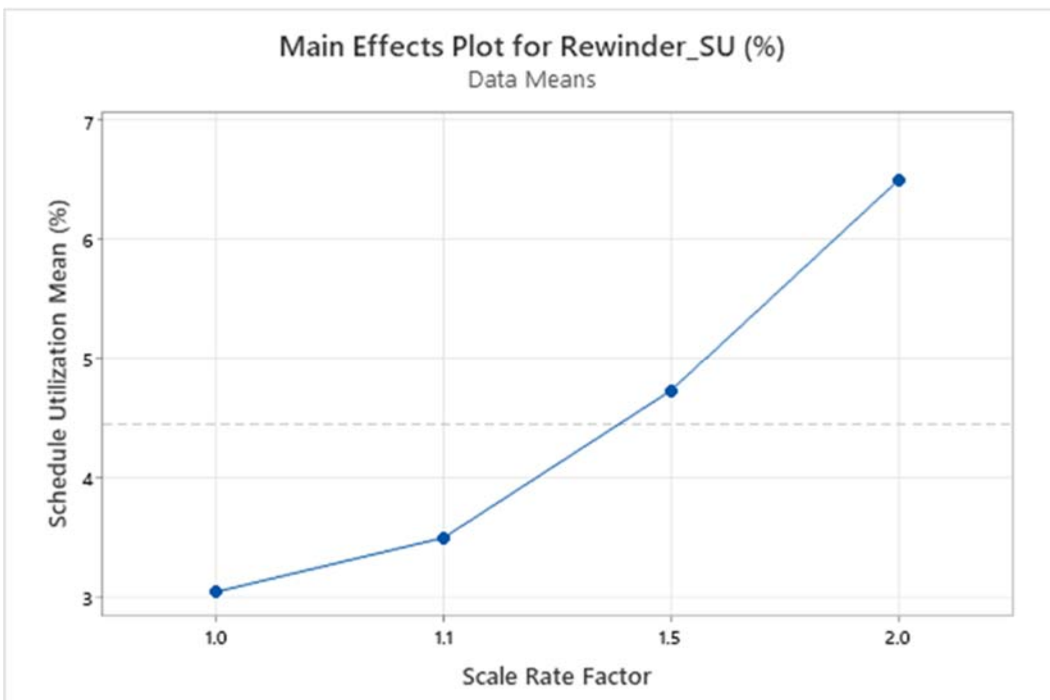


Figure 37.1: Main Effect Plot for Rewinder Schedule Utilization (%) with Scale Factors

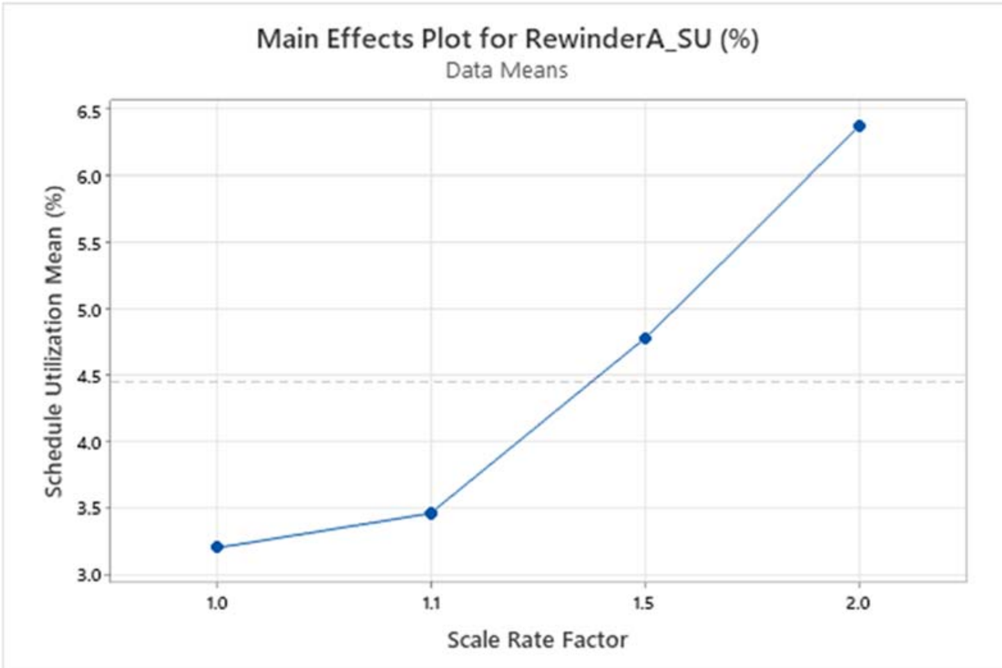


Figure 38.1: Main Effect Plot for Rewinder A Schedule Utilization (%) with Scale Factors

MAIN EFFECT PLOT: SCALE FACTORS FOR MACHINES NUMBER PROCESSED

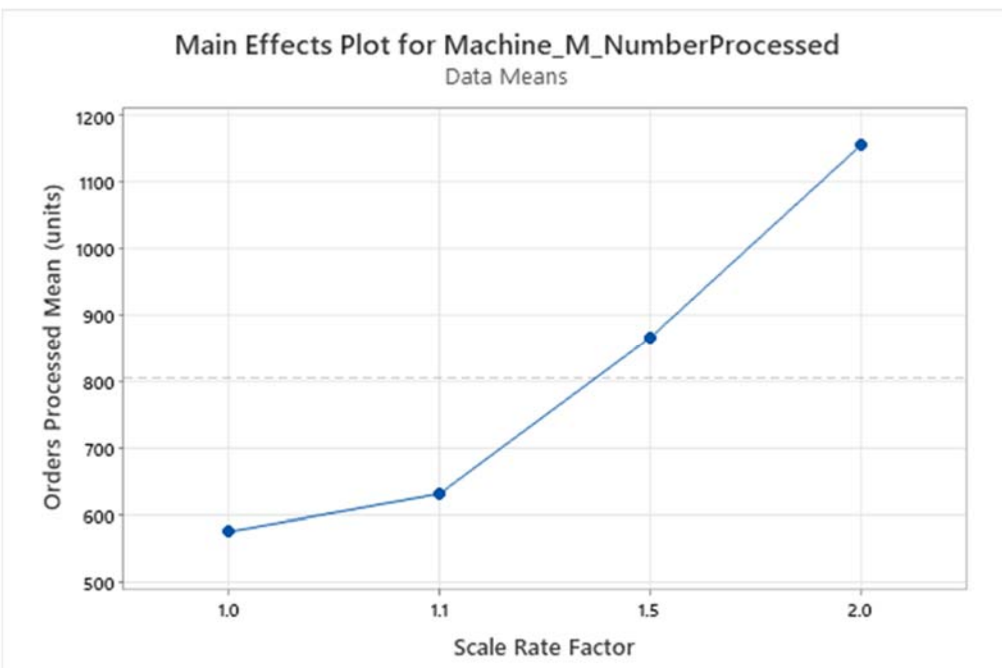


Figure 39.1: Main Effect Plot for Machine M number processed (orders)with Scale Factors

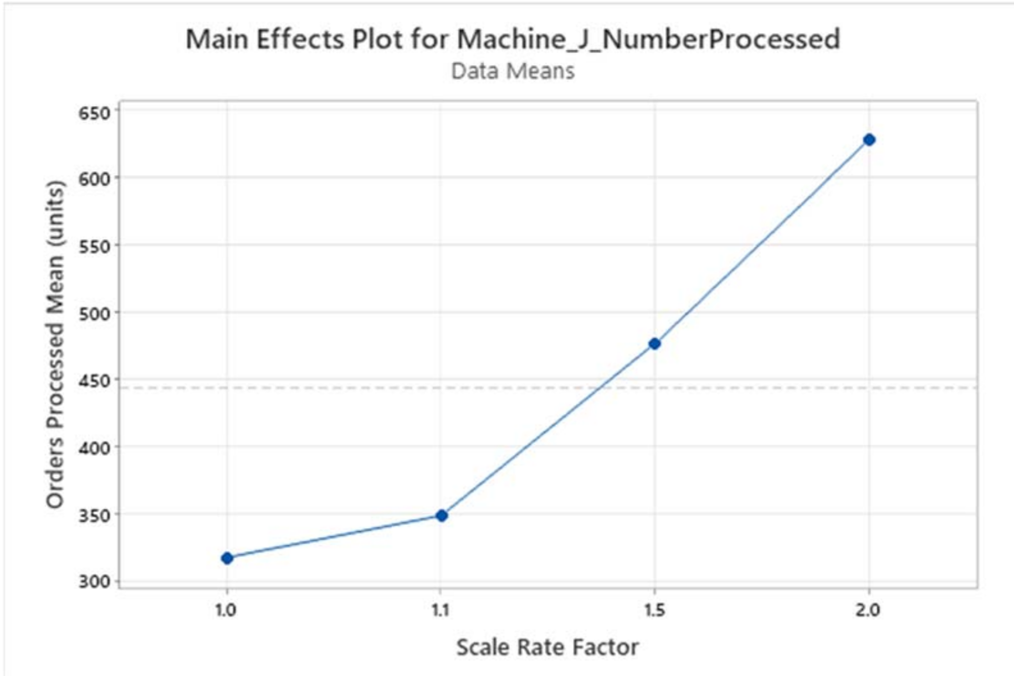


Figure 40.1: Main Effect Plot for Machine J number processed (orders) with Scale Factors

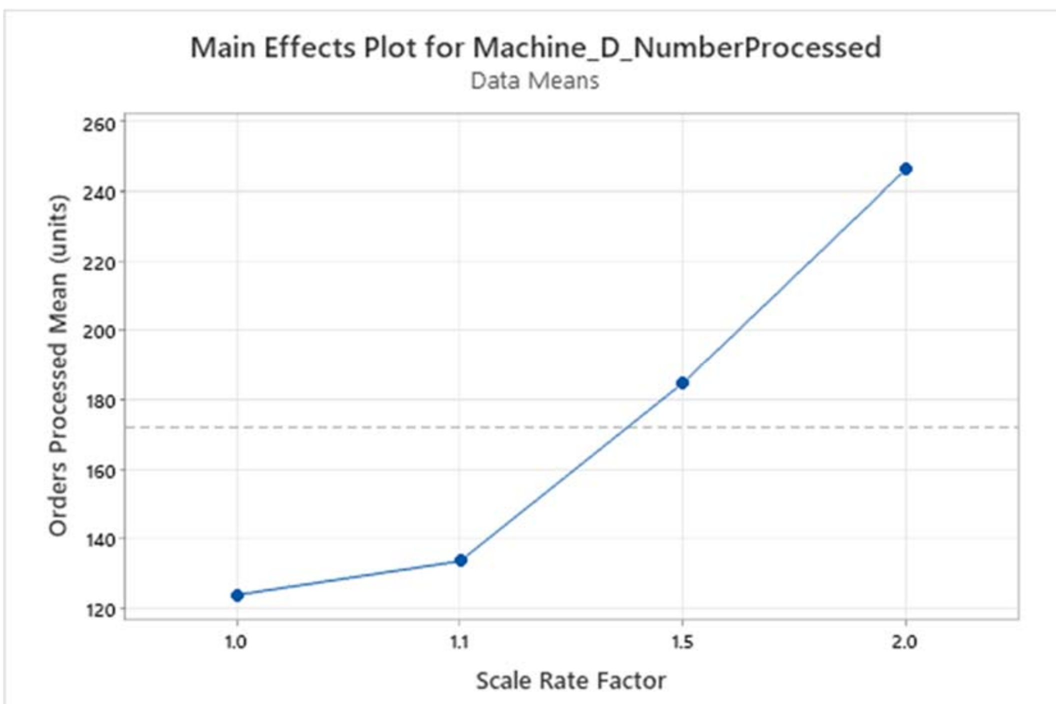


Figure 41.1: Main Effect Plot for Machine D number processed (orders) with Scale Factors

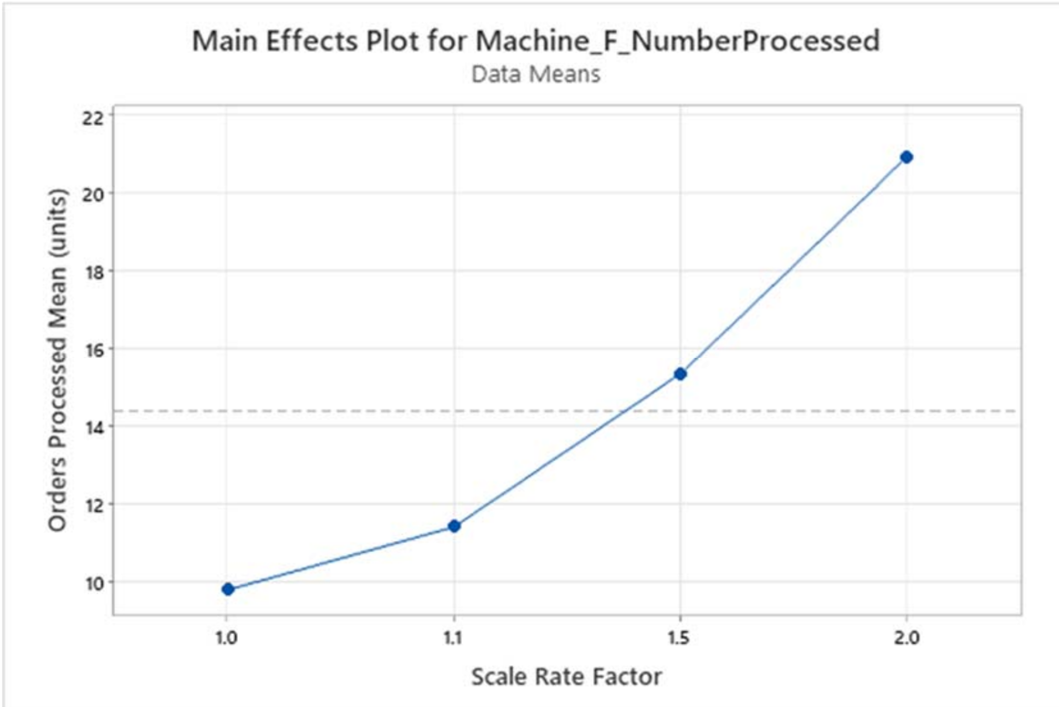


Figure 42.1: Main Effect Plot for Machine F number processed (orders) with Scale Factors

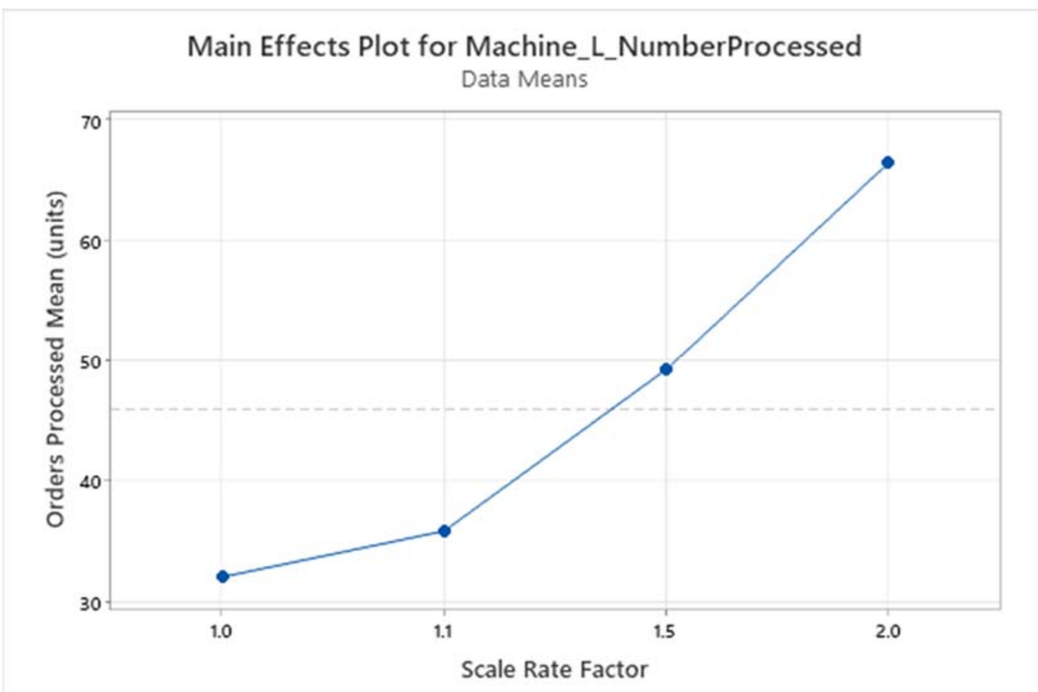


Figure 43.1: Main Effect Plot for Machine L number processed (orders) with Scale Factors

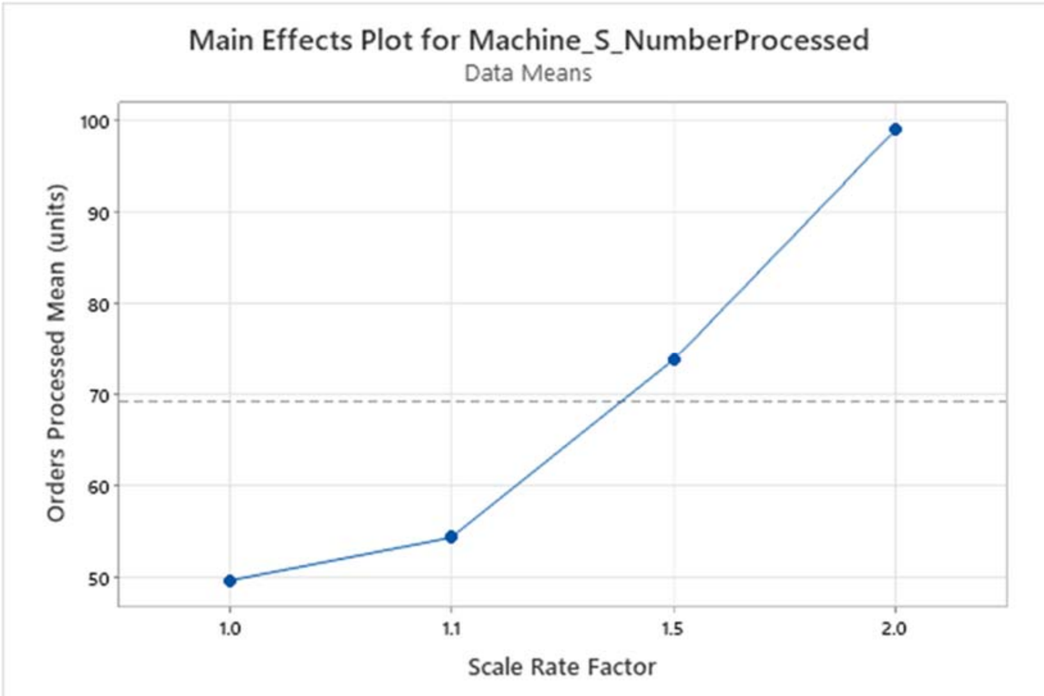


Figure 44.1: Main Effect Plot for Machine S number processed (orders) with Scale Factors

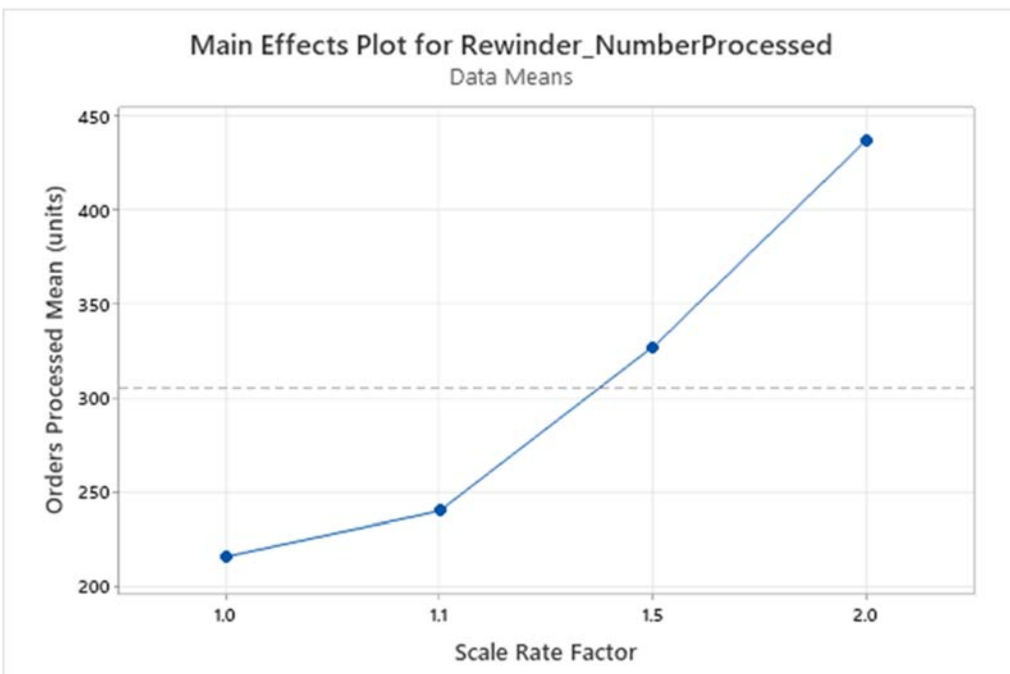


Figure 45.1: Main Effect Plot for Rewinder Number processed with Scale Factors

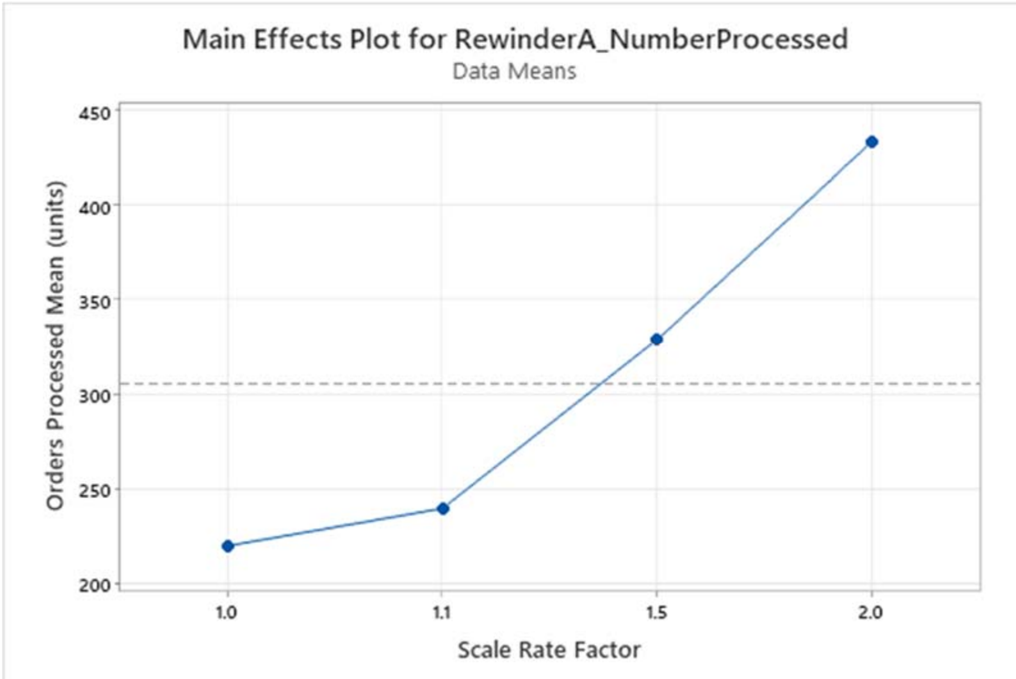


Figure 46.1: Main Effect Plot for Rewinder A number processed (orders) with Scale Factors

MAIN EFFECT PLOT: SCALE FACTORS FOR SINK NUMBER PROCESSED

The selection of a scale factor for machine Number processed is meant to understand the system by incrementing the rate factor by 1.0,1.1,1.5, and 2.0. Main Effect plot analysis conducted to represent the results correlation.

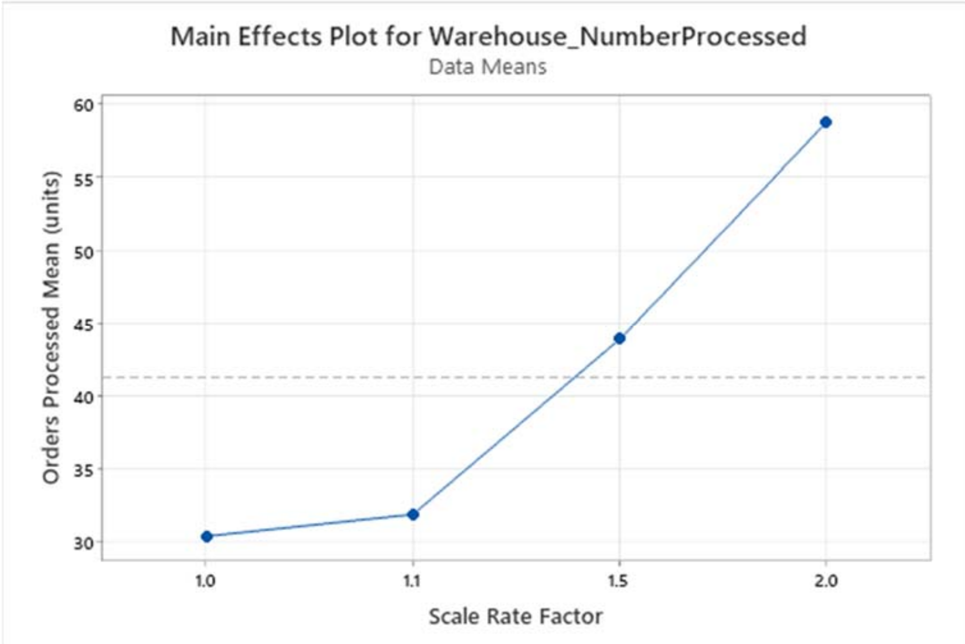


Figure 47.1: Main Effect Plot for Warehouse number processed (orders) with Scale Factors

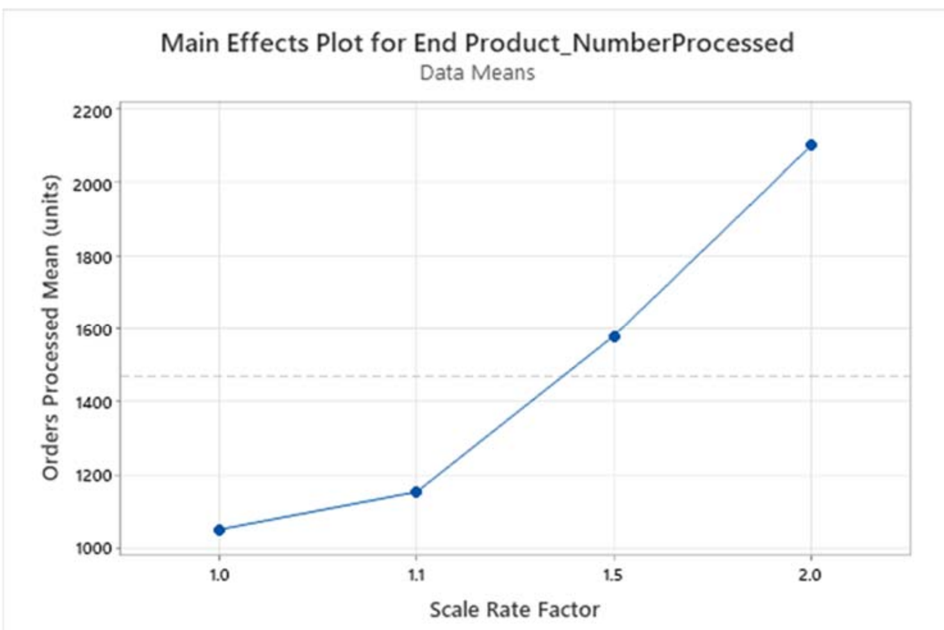


Figure 48.1: Main Effect Plot for End Product number processed (orders) with Scale Factors

INCREMENTATION OF THE RATE SCALE FACTOR IN CURRENT SCENARIO

The incrementation of the rate scale factor will assess the overall model with a Standard Week schedule (8:00 am – 5:00 pm) and the capacity of 1 resource. As per the current scenario schedule utilization measures, machines utilization equipment is below the ideal utilize measures of 75% - 85%. The opportunity in this section is to evaluate the current scenario by incrementing the rate scale factor by 1 to understand the potential scenario. Results show the current scenario can be incremented by a rate factor of 3 to be within the utilization measures.

A rate Scale factor of 3 in table 9.1, displays the machine's schedule utilization (%): Machine_D_SU 86.8495, Machine _M_SU 61.4794, Machine_J_SU 58.6239, Machine_L_SU 18.6826, Rewinder_A_SU, 4.246, Rewinder_SU 4.21198, Machine_F_SU 8.10946, and Machine_S_SU 6.07371.

A rate Scale factor of 3 in table 10.1, assesses the number processed (orders) machines as Machine_M_NP 1723.95, Machine_J_NP 940.1, Machine_D_NP 363.3, Machine_F_NP 31.75, Machine_L_NP 96.7, Machine_S_NP 146.35, Rewinder_NP 646.3, Rewinder_A_NP 652.05.

Entities that enter an input node are ready to ship to a customer. The results as in table 11.1 shows the total orders a system produce if the scale rate factor is an incremented by 3. The warehouse and end product sink count 83.35 and 3134.3 orders, respectively. The analysis, rated with a scale factor of three, still has room for improvement in utilization and capacity performance measures. The schedule utilization per machine in Table 9.1, orders processed with rate scale factor of 3 in table 10.1, and orders processed with rate scale factor of 3 in table 11.1.

Results show Machine D, Machine M, and Machine J are machines with the most orders processed and utilized. Machine F, Machine L, Machine S, Rewinder, and Rewinder A are machines with the lowest number of orders processed and utilized. Machine D is the machine with the highest utilization rate 86% due to high utilization in processing times and number of orders processed. Machine M accounts for 61.5% of the utilization. Demand from Machine D can be supported by Machine M due to similarities in machinery for utilization purposes. The increment of scale rate factor of 3 will set Machine J at 58.6 %, hence, Machine J has opportunity for improvement in reducing the idle time by 25%.

Table 10.1 displays the results of the total orders processed with a rate scale factor of 3 for each machine. The selected scenario is with the scale rate factor of 3. Each machine can be incremented by a rate of 3 which accounts the growth of 34% of performance capacity for all machines. Table 11.1 summarizes the total number of orders processed with a scale rate factor of 3.

Incrementing the rate of a scale rate factor of 3 will be at a stable level of utilization within 85 % utilization and 34 % of orders processed.

Table 9.1: Schedule Utilization Rate Scale Factor of three per machine

Scale Rate Factors	Schedule Week	Machine_D SU	Machine_M_SU	Machine_F_SU	Machine_J_SU	Machine_L SU	Machine_S SU	Rewinder_SU	RewinderA SU
1	StandardWeek	29.3464	20.2638	2.60212	18.9123	5.83393	2.03128	5.4117	6.014
2	StandardWeek	55.8438	41.4837	5.14228	39.2369	11.9908	4.28475	4.28231	4.19237
3	**StandardWeek**	**86.8495**	**61.4794**	**8.10946**	**58.6239**	**18.6826**	**6.07371**	**4.21198**	**4.24671**
4	StandardWeek	98.4918	82.4235	10.5105	74.32	24.3714	8.36948	22.9892	23.0193
5	StandardWeek	99.1016	98.1645	14.3785	89.9873	32.1999	10.3378	10.3664	10.0286
6	StandardWeek	99.6345	99.6906	16.2683	98.4543	38.545	12.3512	7.61467	7.66947
8	StandardWeek	99.7044	99.8621	20.3166	99.6593	50.3128	15.5187	36.4955	36.1209
9	StandardWeek	99.6725	99.85	24.4063	99.7044	56.4086	17.486	13.8998	13.7415
10	StandardWeek	99.7206	99.9095	26.9121	99.7651	64.1564	19.6514	9.6246	9.72455

Table 10.1: Orders Number Processed Rate Scale Factor of 3 per machine

Scale Rate Factors	Schedule Week	Machine_M_NP	Machine_J_NP	Machine_D_NP	Machine_F_NP	Machine_L NP	Machine_S NP	Rewinder_NP	RewinderA_NP
1	StandardWeek	573.15	313.55	125.3	9.7	30.25	50.55	207.35	222.95
2	StandardWeek	1148.9	624.45	240.1	20.6	62.55	98.85	431.45	428.15
3	**StandardWeek**	**1723.95**	**940.1**	**363.3**	**31.75**	**96.7**	**146.35**	**646.3**	**652.05**
4	StandardWeek	2283.1	1245.85	412.6	41.4	126.75	199.4	858.5	861.6
5	StandardWeek	2725.11	1539.42	415.632	54.8421	168	247.684	1075.53	1062.11
6	StandardWeek	2771.79	1750.58	418.842	64	200.684	296.474	1208.42	1232.79
8	StandardWeek	2793.74	1852.16	421.421	78.4211	262.632	379.789	1346.26	1349.37
9	StandardWeek	2800.89	1896.47	422.053	93.6316	296.421	429.211	1420.11	1422.63
10	StandardWeek	2770.5	1875.94	420.222	102.722	318	482.778	1449.83	1455.17

Table 11.1: Orders number processed rate scale factor of 3 per sink

Scale Rate Factors	Schedule Week	Warehouse NP	End Product NP
1	StandardWeek	31.6	1043.6
2	StandardWeek	58.55	2083.5
3	**StandardWeek**	**83.35**	**3134.3**
4	StandardWeek	106.8	4108.95
5	StandardWeek	111.842	4940.63
6	StandardWeek	116.632	5280.11
8	StandardWeek	117.368	5566.79
9	StandardWeek	118.211	5715.63
10	StandardWeek	117.611	5746.39

CHAPTER 5: CONCLUSION

Enhancing simulation models in local industries will help stakeholders make decisions and save money and time. The SIMIO simulation application research imitates the real-world scenario into a virtual simulation system. SIMIO simulation is a sophisticated software with the capabilities to design a system with design model logic, data logic, process logic, scheduling logic, and results in logic. KPIs number processed, schedule utilization, main effect plots, and experiments utilized in this research.

The research concluded in SIMIO Discrete-Event Simulations is a valuable tool used to measure the performance capacity of the industry. The model simulated the current source, sink, and server capacity performance utilizing experiments, replications, and main effect plots to identify the current performance in the manufacturing site. The research findings concluded the labeling manufacturer site could increase total orders processed and schedule utilization by three times the current rate. The demand will be met without purchasing any equipment to meet the system's number processed and schedule utilization performance. By incrementing the facility three times, the manufacturing site will still meet the overall machine utilization of 85%. The research improves the overall facility flow of setup times, schedule utilization, total number of orders processed, and process flow by 34%. Machine D, Machine M, and Machine J are considered high runners. Machine D is within 85% utilization limit, meaning Machine M and Machine J can still handle higher demands. Machine E, Machine J, Machine L, Rewinder, and Rewinder A are considered low runner machines with an opportunity to reduce idle time for 55 - 65% for each machine. DES model was successfully implemented and approved by stakeholders. The opportunity of this model is to continuously improve the current scenario of the facility with new research techniques, optimization tools, statistical analysis, and supply chain methodologies.

FUTURE WORK

The research conducted in labeling manufacturing provides a solid foundation for future research. The research findings allow others to keep exploring the industry by adapting research techniques, optimization tools, statistical analysis, and supply chain methodologies.

The future work will describe below:

- Conduct statistical analysis to verify the means' accuracy in the current and proposed model.
- Evaluate the overall performance of the manufacturing by linking every system in the simulation model.
- Analyze raw material data for lead times and implement methodologies will function as in the current scenario.
- Evaluate the performance of the overall facilities with the implementation of new products and machinery in facility
- Measure the maintenance and failures of the current capacity.
- Continuous Improvement Methodologies- the constant continuous improvement methodologies applied to the current system and labeling industry will be the industry's future success.
- The success of an industry is to research, evolve, digitalize, and continuously improve. The contribution of this research to the labeling industry is a contribution will set solid foundations for future research.

The success of an industry is to research, evolve, digitalize, and continuously improve. The contribution of this research to the labeling industry is a contribution will set solid foundations for future research. Small contributions today will be the success of tomorrow.

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VITA

Joshua Holguin was born and raised in El Paso, Texas/Ciudad Juarez, Mexico. He holds a bachelor's degree in Industrial and Systems Engineering from the University of Texas at El Paso (UTEP). During his undergraduate studies, Joshua was fortunate to study abroad in Mexico and Costa Rica, Intern for Cardinal Health and Johnson & Johnson, compete in the Arkansas Judging Pit, participate in the Louis Stokes Alliance for Minorities and American Association of Hispanics in Higher Education conferences, and do research in the Louis Stokes Alliance for Minorities Program and the UTEP Industrial, Manufacturing, and Systems Engineering Department. After graduating, he decided to join the master's degree in manufacturing engineering program to acquire more manufacturing insights and skills. Worked alongside with Dr. Madathil as a Research Assistant student working with simulation models and proctoring classes. Currently, Joshua works for Cardinal Health in the medical industry as a Product Engineer. Joshua's goals are to apply knowledge learned in education and apply them in his engineering role.