

Improving Production Efficiency and Material Flow Using AGV Simulation: Insights for Manufacturing Business Operations

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Abstract

In today's competitive manufacturing environment, efficient material flow plays a critical role in ensuring business productivity and operational continuity. This project focuses on enhancing the material handling system of a production and assembly line by optimizing the performance of the existing Automatic Guided Vehicle (AGV) system. Frequent line stoppages due to delayed material supply have been identified as a key issue impacting throughput and efficiency. To address this, a simulation-based approach was employed using Siemens Tecnomatix Plant Simulation to model, analyze, and optimize the AGV system. Through detailed scenario testing and data-driven analysis, improvement strategies were developed and assessed to reduce delays and improve material flow reliability. The findings highlight actionable insights into how AGV optimization can support leaner operations and minimize disruptions in a manufacturing setting. The proposed strategies offer practical benefits for production efficiency and provide a framework for enhancing overall business performance through simulation-driven decision making.

Keywords: Automatic Guided Vehicle System, Discrete-Event Simulation, Optimization, Business operations, Production and Assembly Efficiency

Introduction

In the era of globalized competition and rapidly shifting market demands, **manufacturers are under increasing pressure to enhance production flexibility, efficiency, and responsiveness.** Modern production systems are expected to deliver high product variety, shortened delivery times, and leaner operations often with limited resources and rising complexity (Asadzadeh, 2015; Niehues et al., 2015; Allahverdi et al., 2018). Achieving this requires advanced methods and technologies for optimizing material handling and internal logistics, especially in assembly-intensive manufacturing operations.

One of the most critical enablers of efficient, lean, and responsive manufacturing operations is the Automatic Guided Vehicle (AGV) system, which plays a foundational role in modern automated material handling. AGVs are driverless, computer-controlled vehicles designed to transport materials along predetermined routes within production or warehouse facilities. Equipped with advanced navigation technologies including laser guidance, magnetic tape, RFID sensors, or vision-based systems AGVs can move with precision and reliability across complex shop floors, adapting to various operational layouts and demands (Tanchoco, 1991; De Ryck et al., 2020).

The strategic significance of AGVs lies in their ability to automate repetitive and time-sensitive transport tasks, thereby relieving human workers of labor-intensive duties and minimizing human error. This automation results in multiple operational benefits: improved labor efficiency, increased workplace safety, reduced production downtime, and streamlined internal logistics (Schulze, 2008; Zhang & Liu-Henke, 2020). AGVs can ensure consistent and timely delivery of components and subassemblies between key production areas, such as from raw material warehouses to production cells, or from final assembly lines to packaging and storage zones (Sooriyakumar et al. 2023; Vlachos et al. 2024). In high-volume manufacturing, where just-in-time (JIT) principles are applied, AGVs are essential for maintaining flow balance, avoiding bottlenecks, and synchronizing production stages (Yao et al. 2020). Beyond their logistical function, AGVs also support data collection and system integration in smart manufacturing environments. When integrated into Cyber-Physical Production Systems (CPPS) or Industry 4.0 frameworks, AGVs can communicate with manufacturing execution systems (MES), adapt to real-time scheduling changes, and respond to production variability. This integration enhances system responsiveness and contributes to the development of adaptive, self-regulating production ecosystems, a key requirement for mass customization and dynamic order fulfillment.

Given these advantages, AGVs are not merely auxiliary equipment but are becoming central to the design and operation of modern, agile manufacturing systems (Stefanini & Vignali, 2022). As industries pursue greater automation and digital transformation, the role of AGVs continues to evolve shifting from simple transport units to intelligent, interconnected nodes within the broader production system (Oyekanlu et al. 2020; Larsson & Delvén, 2023). Thus, optimizing AGV performance is not only necessary for short-term efficiency but also critical to long-term competitiveness and scalability.

However, as production volumes increase and system complexity rises, even well-established AGV systems can become bottlenecks if not continuously monitored and optimized (Mousavi, 2018; Bhargava et al. 2024). This challenge was evident in a **business printer manufacturing company** that had implemented an AGV system to support its assembly line operations. Due to poor material flow, the factory experiences issues with order delays at the assembly workstations. The production line must halt while it awaits the delivery of the part. Unplanned breaks result in lower output and operating profit. The company's delivery output was insufficient as a result of the rising order demand and the slow AGV production movement. There was a chance that the delivery would be delayed as a result. The AGV system doesn't appear to be able to produce at the necessary rate. However, this AGV system makes sure that there is constant material flow during the manufacturing and assembly processes. Therefore, the AGV system's congestion should be reduced without

jeopardising material flow. New strategies to enhance the AGV system for the material flow may barely be evaluated by application in the current production due to the complexity of the production and assembly process. Even minor modifications might have unpredictable results, and unforeseen challenges may force unplanned production halts. Given the critical nature of uninterrupted material flow in maintaining production continuity, there is a **clear need to evaluate and optimize AGV performance in dynamic manufacturing settings**. However, due to the inherent complexity of real-world production environments, implementing changes directly on the shop floor can be risky, costly, and disruptive. This underscores the value of **simulation-based optimization**, which allows for virtual experimentation and analysis of system improvements without impacting live operations.

This study explores how **Siemens Tecnomatix Plant Simulation** a discrete-event simulation tool was used to model, analyze, and optimize the AGV system at the company. The software enables users to simulate complex factory operations, identify inefficiencies, and assess the impact of proposed changes in a risk-free digital environment (Mourtzis et al., 2014; Lugaresi & Matta, 2018; Morris et al., 2019). By using Siemens Tecnomatix Plant Simulation, a digital replica of the production environment was constructed to represent real-time material movements, process interactions, and operational constraints. This was used to conduct controlled virtual experiments and assess the system's behavior under various loading and routing conditions.

The primary objective of this research was to develop a comprehensive simulation model of the factory's internal material flow system, with a particular focus on evaluating and optimizing the performance of its existing AGV configuration. The study concentrated specifically on PHASE 4 of the production line, a critical segment that had been plagued by frequent material flow disruptions, resulting in significant delays, unplanned idle time, and reduced output. This area was identified as a bottleneck that had a cascading effect on downstream processes, ultimately affecting the factory's ability to meet delivery targets. By simulating both the current state and multiple enhanced configurations, the research aimed to identify the root causes of AGV congestion, such as inefficient path layouts, poor task scheduling, or inadequate vehicle availability.

Through iterative scenario testing and comparative performance analysis, the simulation generated quantitative insights into how proposed changes such as route optimization, task prioritization algorithms, and increased AGV fleet size could improve material flow efficiency, reduce lead times, and enhance overall system responsiveness. These results provided data-driven, low-risk guidance for decision-makers seeking to implement physical changes on the production floor without disrupting ongoing operations.

Beyond its immediate practical application, the study demonstrates how simulation modeling can serve as a strategic tool in modern manufacturing for continuous improvement and proactive problem-solving. The findings not only inform operational decisions at the case company but also offer transferable methodologies that can benefit similar manufacturing environments facing logistical inefficiencies. In doing so, the research bridges the gap between digital innovation and real-world industrial performance.

This research is particularly valuable for **plant managers, industrial engineers, and operations strategists** who seek to leverage digital tools for continuous improvement in material handling and logistics. It also contributes to the academic and industrial discourse on **smart manufacturing**, illustrating how simulation technologies can be integrated into production planning to support data-driven decision-making, lean operations, and long-term competitiveness.

Literature Review

Production Management

The planning activities for the factory layout and material flow for the production plant are all included in the production management activities on one hand. On the other hand, regulating these operations guarantees that the output is productive and efficient (Kumar and Suresh 2006; Schumacher et al. 2020). Production management oversees manufacturing and supervises production inputs like raw materials, capital, and labour to produce desired outputs, such as products (Fera et al. 2013). Management of production is crucial in manufacturing, regardless of the size of the company. As a business grows and the difficulty of managing projected output rises, this becomes increasingly important (Netland et al. 2021; Salah et al. 2023).

Functions of Production Management

The most crucial duties include cost engineering, production planning and control, material planning and control, quality assurance, and product development and technology planning.

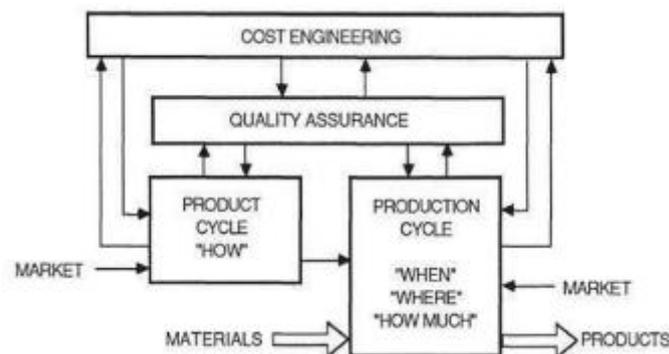


Figure 1: Connection between Production Management Functions

Given that these tasks are crucial for the product cycle and the production cycle shown in Figure 1, their importance for manufacturing businesses becomes clear. By using a well-structured production management strategy, businesses may boost productivity and cut costs, giving them a competitive edge in the market (Dankbaar 1988).

AGV System

When forklifts, conveyor systems, or manual carts aren't an option, automated guided vehicle systems are utilised to move significant amounts of goods repeatedly. AGVs can be used for a variety of purposes. Raw commodities including paper, rubber, plastic, metal, and rubber are routinely transported using them (Lee and DiCesare 1994). Without human intervention, AGVs continuously and reliably supply the raw materials required, ensuring that production lines never run out of what they need. AGVs are used to support production or

manufacturing lines by moving finished goods as well as work-in-process materials. Collaborative mobile robots such as AGVs guide warehouse workers through their tasks and deliver chosen orders to workstations for packaging and shipping, aiding in picking.

AGVs take the place of humans in the transportation of materials and items on the factory floor. As a result, AGVs can tackle risky duties like operating in chilly conditions, handling hazardous products, and moving big loads. Additionally, these autonomous vehicles travel at monitored speeds while accelerating or decelerating steadily and smoothly. In contrast to conventional forklifts, which operate at varying speeds and may harm workers, AGVs have controlled operations. AGVs are therefore essential for improving plant floor safety. Human employees are prone to mistakes, particularly when they are fatigued or distracted. These robots avoid collisions by stopping when they detect an obstruction using cameras, sensors, and lasers. Any plant floor needs a way to track inventory, and AGVs can provide quality material handling. Floor managers can integrate AGV systems with warehouse management or control systems to track inventory automatically. The cost of inventory management will decrease because of such system integration. Additionally, it will lead to greater efficiency and precision, enabling management to know precisely how much raw materials and completed goods they have on hand.

The high expense of implementing this new technology is one of the most difficult aspects of installing AGVs. A guidance system for the floor must be installed in addition to the price of the AGV itself. AGV installation costs can include training expenses for maintenance staff and handling people. The quantity of AGVs, the size of the plant floor, and the software the AGV will utilise are other variables that will affect the overall cost. AGVs' lack of adaptability is their biggest drawback. AGVs are best suited for repetitive tasks because of their limited flexibility (Schulze et al. 2008; De Ryck et al. 2020). In contrast to humans or autonomous mobile robots, which may react and modify their jobs or adjust their speed, AGVs are fixed-route robots that are embedded into the plant floor. AGVs cannot be used for floor operations like selecting that call for some degree of flexibility. To function properly, AGVs require specific working conditions (Zhang and Liu-Henke 2020)

AGV's Effect on the Flexible Manufacturing System (FMS) in a Stochastic Environment

In 1974, the Volvo plant in Kalmar, Sweden, implemented the AGV System for the first time on a significant production scale. This becomes an essential component of the FMS's material handling system. Because the AGV system offers the versatility and flexibility needed in an FMS environment for a material handling system. The expense of implementation is the only obstacle to the use of AGVs, but most of the time there are no technical problems. To evaluate the effectiveness and increase the efficiency of the AGVs, extensive research has been conducted. AGV performance is evaluated in a variety of methods by various studies. Simulation was utilised by Taghaboni-dutta and Tanchoco (1995) to examine the efficacy of a novel dynamic approach for the routing of AGVs.

For the comparison of single and multi-attribute dispatching rules. Klien and Kim (2018), chose several measures such as queue length and load waiting time in each department, vehicle travel time, and job completion time. The scheduling and routing of the system's vehicles is one of several elements that have an impact on an AGV's effectiveness. The effectiveness of the system was examined in terms of the distance travelled and the time

needed for AGVs to complete the task. The performance of dispatching rules changes with the journey time in an AGV-based flexible manufacturing system. A design methodology for AGV systems using multiple loads was developed by Ho and Hsieh (2004). They create a mechanism that can reduce flow distance, achieve inter-loop flow, and balance the workload among cars in various loops. To reduce the overall trip distance on the loop, a single loop system with at least one edge sheared with the cell, direction of flow, and position of pickup/drop-off stations on the loop. They used the Tabu search approach an integrated algorithm created by Fred W. Glover for creating system facilities and a material handling system in an FMS. The single-loop AGV system was their main concern. Block layout, single-loop AGV flow path, and loading/unloading stations are further problems that can be solved by the created method. A method that simultaneously calculates the routing of AGVs and machine layout was created by Rezapour et al. (2011). According to Sharma and Sushil (2004), the FMS is a time-consuming and difficult capital investment process. They also talked about several essential elements needed to build a flexible manufacturing system. Even so, it is a difficult issue to fully implement an AGV-based material handling system in FMS. Using the commercial standard ISA-95, Eduardo created a hybrid control architecture for the group of AGVs in the FMS that was based on the Petri net concept. They chose a methodical strategy that applies the discrete-event system paradigm to manufacturing. Although computer-controlled automated material handling systems are more adaptable and competent than non-automated systems, implementing and managing such systems presents significant operational hurdles. In an AGV-based material handling system in the FMS, Demesure et al. (2016) suggested a new method of mobile agent navigation. To resolve disputes, they also created the priority policy negotiation procedure. Simulations are useful in demonstrating the system's viability as the number of mobile agents rises. Regarding this, Sabattini et al. (2017) developed a novel cloud robotics architecture that enables vehicle movement on the shop floor in the context of the smart industrial system. A location system for AGVs using radio frequency identification is presented by Lu et al. (2017). Optimisation of the AGV fleet size is a crucial component of a successful system design. For any FMS, Chawla et al. (2018) employed the grey wolf optimisation technique to determine the ideal AGV fleet size. Through computer tests, they also verified the outcomes for the various FMS layout sizes. In light of the aforementioned context, this work specifically investigates the impact of AGV fleet size, AGV velocity, system capacity, and sequencing rule on an FMS's performance concerning MST and RU in a stochastic manufacturing system.

Simulation

According to Browne (1988), simulation is a research-based technique that seeks to create a model that reflects the behaviour of a complex system. The amount and calibre of the supplied data affect the model's accuracy (Nasiri et al. 2017). There is a wide spectrum of simulation model complexity, with the most sophisticated models reflecting production systems to a very high degree (Korytkowski et al. 2013; Sivarat and Apichat 2021).

The two primary categories of simulation are continuous simulation and discrete event simulation (DES) (Abdul Rahman et al. 2022). The clock in DES is based on events rather than having a running time like continuous simulation does. Only when the clock jumps from one event to the next will the state changes be monitored. DES, a key piece of equipment for Industry 4.0, makes it possible to analyse production and supply chain systems effectively (Mourtzis, 2020).

For DES, there are primarily two uses. On the one hand, production management systems can leverage DES as a design tool. However, DES can also serve as a tool for supporting decisions through analysis. Similar to this, Mourtzis (2020) stresses the value of DES in planning and decision-making in businesses. As a result, the range of applications is vast, including optimization of agricultural layouts, production reliability models, warehouse planning, and production planning (Siderska, 2016).

Problem Formulation and Method

This project aimed to study improvement that can be applied to an automated guided vehicle (AGV) system at a printing device manufacturing company using discrete-event simulation software. The project focused on the issue of an efficient AGV system being required in a manufacturing facility. AGV system placement issues resulted in delays for orders at the assembly workstations, which is problematic for production management. Unplanned breaks result in lower output and operating profit. The AGV system doesn't appear to be able to produce at the necessary rate. To prevent these problems, an upgraded AGV system should be put in place. Therefore, improvement approaches need to be tested before being installed and used in the production factory. PHASE 4 needed to be improved. Tecnomatix Plant Simulation Software is employed for this purpose. The study followed several key steps. Initially, the AGV system is simulated, and the digital model is examined using Tecnomatix Plant Simulation. This involved updating station parameters for performance analysis. The simulation identified potential issues like congested AGV paths or bottlenecks in facility areas. Once the issues were identified, objectives were set, considering performance, profit, or inventory-related goals. The subsequent steps involve model building and data collection, with the model's complexity inversely proportional to the required data volume. Experimentation and analysis followed, comparing alternative models' performance to the existing system, and analysing AGV system data. The simulation helped in identifying congested routes or bottlenecks and guiding improvements.

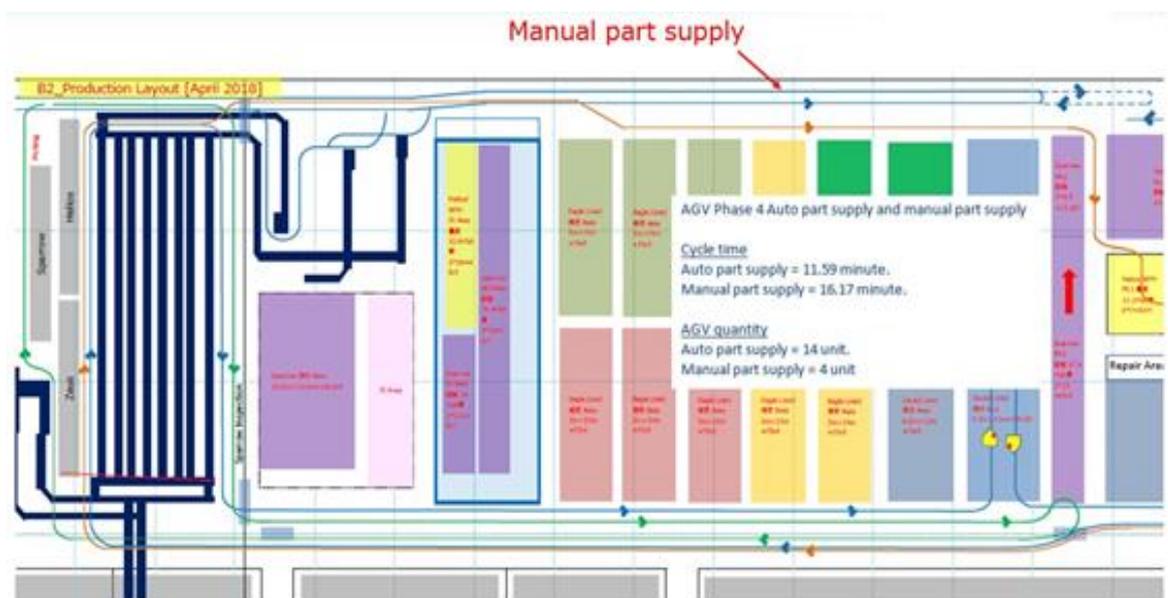


Figure 2: Layout of PHASE 4

Model Conceptualization

Model conceptualization for the production and assembly process has been elementary for the simulation as it has preliminarily defined the objects and variables that constitute the system. For this research project, the simulation model does not comprise the entire production of the business printers, but only the objects and the material flow related to the functional units of the production and assembly process. This is in coherence with the scope of the objective. Consequently, all workstations which are involved in the material flow for the functional units have been involved in the model. According to this simplification, the model has been conceptualized based on the factory layout. Thereby, the conceptualized model needs to comprise the characteristics of the production and assembly process. For model conceptualization, it has been important to define all workstations involved in the production and assembly process as preparation for the data collection and model translation in this project. The plant layout is illustrated in Figure 2 for PHASE 4. In the following paragraphs, there will be described the material flow entities as well as the overall flow and current strategy used for the production and assembly process. To conceptualize the model for the production system it was important to understand the AGV cycle process. Starting from the order made by an operator at the assembly line, the parts are sent from the warehouse to two loading points through conveyors. Next, the AGV will pick up the parts and send them to the respective assembly line and wait for the unloading process and for loading empty boxes at the next stop. There are seven stations for Phase 4. After that, the AGV goes to the warehouse to unload empty boxes and returns to the AGV station, waiting for the next order.

Data Collection and Data Analysis for PHASE 4

Since the reliability of the simulation model is correlated with the calibre of the input data, data preparation and collecting have been fundamental to the project (Mutawe. To create a simulation model that can reflect the production system, data for each object has been prepared and carefully chosen. Data collection and interpretation are crucial elements in the simulation modelling process. Data is collected from a printing device manufacturing company. It contains the number of days, order time and interarrival times. The simulation software was used for the data fitting and goodness-of-fit test. Table 1 depicts the data collection for each source in this project. Since there are 7 types of parts, assume that each station will only receive 1 type of product to prevent an overlap situation. For example, Part (Part_S00 – Part_S06) will move to Station (S00-S06) respectively and each source has a different distribution. Since multiple orders are placed simultaneously, will combine them, and treat them as a single order to prevent data fit errors.

Data Fit Analysis for PHASE 4

The DataFit object in the simulation software was used to fit the data to a distribution. This object was created expressly to fit a distribution to a data input. The object provides for the input of data from a data file in a list, as well as whether the input data is continuous or discontinuous, comma or point separated. Additionally, the object enables data filtering before allowing the user to provide appropriate parameters for the "Goodness-of-fit test." A test for the goodness of fit for a categorical variable is the chi-square goodness of fit test. A statistical model's "goodness of fit" refers to how well it matches a set of observations. When the goodness of fit is strong, the values predicted by the model are reasonably close to the values observed. The values predicted by the model and the observed values diverge when

the quality of fit is low. Distributions make up the statistical models that the chi-square goodness of fit tests examine. They can have any type of distribution, ranging from the straightforward equal probability for every group to the intricate probability distribution with numerous characteristics.

Table 1
Data collection for each source

400(Day1)		400(Day2)		401(Day1)		401(Day2)		402(Day1)		402(Day2)		403(Day1)		403(Day2)		404(Day1)		404(Day2)		405(Day1)		405(Day2)		406(Day1)		406(Day2)	
Order Time	Interarrival time																										
8:15 AM	69	7:44 AM	3	7:47 AM	5	12:57AM	22	7:42AM	3	1:19 AM	24	7:49 AM	8	4:39 AM	27	7:45 AM	23	7:47 AM	6	7:45AM	37	1:19 AM	24	7:46 AM	37	7:26AM	21
9:24 AM	26	7:48 AM	21	7:54 AM	5	1:19AM	6	7:45AM	6	1:43 AM	41	7:57 AM	14	8:07 AM	51	8:09 AM	1	7:54 AM	5	8:20AM	4	1:43AM	41	8:23AM	46	7:48 AM	93
9:51 AM	16	8:09 AM	83	8:01 AM	5	1:28AM	9	7:51AM	27	2:26 AM	4	8:11 AM	29			8:19 AM	36	7:59 AM	11	8:24 AM	12	2:26 AM	4	9:10 AM	71	9:21 AM	2
10:08 AM	39			8:06 AM	53	1:37AM	31	8:23AM	15	2:30 AM	5	8:41 AM	574			8:56AM	25	8:10AM	38	8:36 AM	32	2:30 AM	5	10:21 AM	18		
10:48 AM	64			9:03 AM	81	2:08AM	15	8:39AM	4	2:35 AM	9	6:15 PM	323			9:22 AM	65	8:49AM	3	9:09 AM	53	2:35AM	9	10:40 AM	181		
11:52 AM	89			9:15 AM	2	2:24AM	2	8:42AM	31	2:45 AM	32	11:39PM	1			10:28 AM	11			10:02AM	11	2:45 AM	32	1:43 PM	6		
13:22 PM	6			9:17 AM	4	2:27AM	2	9:13AM	5	3:18 AM	3					10:40 AM	33			10:13AM	11	3:18AM	3				
14:22 PM	78			9:24 AM	86	2:29AM	7	9:19AM	12	3:22 AM	76					11:13 AM	48			10:25 AM	15	3:22AM	76				
15:40 PM	8			9:29 AM	90	2:36AM	11	11:02AM	44	4:40 AM	9					12:03PM	98			10:59 AM	19	4:40 AM	81				
15:49 PM	3			10:11 AM	12	2:48AM	28	11:47AM	88	6:01AM	46					1:41 PM	2			11:00AM	2	6:01 AM	46				
15:52 PM	71			10:24 AM	2	3:19AM	3	13:18PM	14	6:47 AM	2					1:44 PM	19			11:05 AM	2	6:47 AM	2				
17:05 PM	5			10:26 AM	5	3:22AM	2	13:32PM	32	6:50AM	57					2:03 PM	4			11:08 AM	128	6:50AM	57				
17:10 PM	63			10:32 AM	4	3:24AM	74	14:06PM	4	7:47AM	29					2:08PM	21			1:18 PM	3	7:47 AM	29				
18:13 PM	6			10:38 AM	146	4:40AM	80	14:10PM	5	8:17 AM	4					2:30 PM	44			1:39 PM	34	8:17AM	4				
				10:43 AM	54	6:00AM	47	14:16PM	31	8:26 AM	4					3:15 PM	28			2:24 PM	70	8:24 AM	2				
				11:38AM	3	6:47AM	3	14:48PM	16	8:29AM	2					3:43 PM	4			3:34 PM	12	8:26 AM	2				
				11:42AM	4	6:51AM	7	15:05PM	43	8:31 AM	36					3:48 PM	38			3:46 PM	7	8:29 AM	2				
				11:45AM	17	8:01AM	6	15:48PM	2	9:08 AM	9					4:27 PM	7			3:54PM	37	8:31 AM	36				
				12:03AM	2	8:11AM	29	15:51PM	38	9:17 AM	13					4:34 PM	30			4:32 PM	6	9:08 AM	9				
				12:23AM	56	8:38AM	5	16:29PM	26							5:05 PM	49			4:39 PM	18	9:17 AM	13				
				1:20PM	6	8:44AM	24	16:56PM	73							5:54 PM	29										
				1:27PM	3			18:10PM	34							6:24PM	8										
				1:30PM	3			18:44PM	63							6:32 PM	8										
				1:34PM	5			19:48PM	3							6:41 PM	7										
				1:41PM	23			19:53PM	3							6:50 PM	4										
				2:04PM	17			19:57PM	4																		
				2:23PM	363			20:01PM	3																		
				2:26PM	7			20:05PM	13																		
				2:34PM	8			20:18PM	2																		
				2:42PM	5			20:39PM	91																		
				2:48PM	25			22:10PM	88																		
				3:13PM	8																						
				3:22PM	422																						
				3:32PM	442																						
				3:50PM	2																						
				3:52PM	45																						
				4:38PM	13																						
				4:51PM	11																						
				5:02PM	2																						
				5:23PM	46																						
				6:10PM	115																						
				8:05PM	13																						
				8:18PM	2																						
				8:39PM	52																						
				9:32PM	35																						
				10:10PM	89																						
				11:40PM	3																						

Table 2

Summary of distribution fitting results

TYPE OF DISTRIBUTION	400			401			402			403			404			405			406		
	Chi	KS	AD																		
Cauchy	-	F	F	F	F	F	F	F	F	F	F	F	-	F	F	-	F	F	-	F	F
Erlang	-	T	T	F	F	F	F	F	T	T	F	T	T	T	T	T	T	T	-	T	T
Gamma	-	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	-	T	T
Gumbel	-	T	T	-	F	F	-	T	T	-	T	T	-	T	T	-	T	T	-	T	T
Logistic	-	T	T	F	F	F	T	F	F	T	T	T	T	T	T	F	T	T	-	T	T
Loglogistic	-	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	-	T	T
Lognormal	-	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	-	T	T
Negexp	-	T	T	F	F	F	T	T	T	-	T	T	T	T	T	T	T	T	-	T	T
Normal	-	T	T	F	F	F	F	F	F	-	T	T	T	T	T	F	T	T	-	T	T
Paralogistic	-	T	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	-	T	T
Pareto	-	T	F	F	F	F	F	F	F	F	F	F	T	T	F	F	T	F	-	T	T
Triangle	-	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	-	F	F
Uniform	-	T	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	-	F	T
Weibull	-	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	-	T	T

CHI	Chi-Square
KS	Kolmogorov-Smirnov
AD	Anderson Darling

T	True
F	False

Table 3

Combination of the three types of distribution with parameters

Gamma Distribution					
Source Name	Part Name	Level of significant	Number of Classes	Alpha (min)	Beta (min)
Source_S0	Part_S00	0.05	20	1.0129	37.7459
Source_S1	Part_S01	0.05	20	0.8132	81.4473
Source_S2	Part_S02	0.05	7	0.9243	26.5706
Source_S3	Part_S03	0.05	7	0.4529	293.4675
Source_S4	Part_S04	0.05	20	1.0421	21.6862
Source_S5	Part_S05	0.05	6	0.8984	27.5476
Source_S6	Part_S06	0.05	20	0.9960	58.6025
Weibull Distribution					
Source Name	Part Name	Level of significant	Number of Classes	Alpha (min)	Beta (min)
Source_S0	Part_S00	0.05	20	1.0352	38.7451
Source_S1	Part_S01	0.05	20	0.8249	58.2687
Source_S2	Part_S02	0.05	7	0.9346	23.7777
Source_S3	Part_S03	0.05	7	0.5775	78.8024
Source_S4	Part_S04	0.05	20	1.0125	22.7207
Source_S5	Part_S05	0.05	6	0.9134	23.6534
Source_S6	Part_S06	0.05	20	0.9363	51.2178

Lognorm Distribution					
Source Name	Part Name	Level of significant	Number of Classes	Mu (min)	Sigma (min)
Source_S0	Part_S00	0.05	20	45.4656	83.9832
Source_S1	Part_S01	0.05	20	62.3295	104.2792
Source_S2	Part_S02	0.05	7	27.1059	49.2223
Source_S3	Part_S03	0.05	7	183.8850	1079.0543
Source_S4	Part_S04	0.05	20	25.1737	41.6441
Source_S5	Part_S05	0.05	6	27.4638	51.5675
Source_S6	Part_S06	0.05	20	66.0729	143.8237

Model Layout Design PHASE 4

AGV system model was captured in Tecnomatix Plant Simulation software. It consists of 4 sections as described in the process flow model: AGV scheduling, 7 sources, loading station and unloading stations. Figure 3 shows the layout of the AGV simulation model using Tecnomatix software.

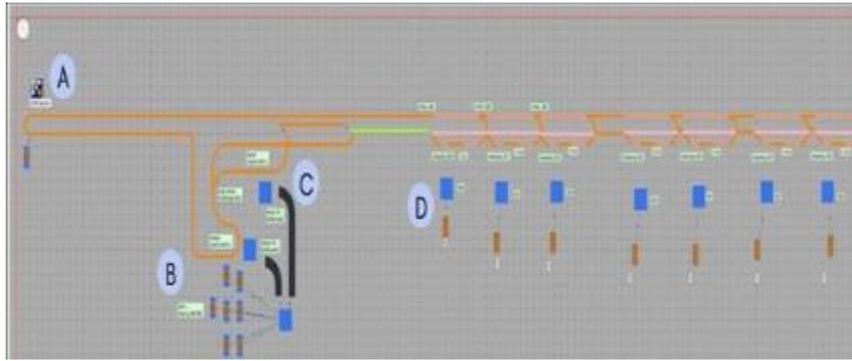


Figure 3: Existing AGV PHASE 4 layouts

Model Programming PHASE 4

This part will concentrate on programming models in the AGV system. It is divided into two parts which are part 1 and part 2. Part 1 describes the distribution of AGVs between Buffer load 1 and Buffer load 2, inspects whether the AGV is occupied or not and loads the parts from a conveyor to a buffer, then transfers them to AGV while Part 2 describes the inspection AGV for each station, unloading the parts and loading the empty box onto AGV. Figure 4 depicts part 1 of model programming in the AGV system while Figure 5 illustrates part 2 of modal programming in the AGV system. Part 1 and Part 2 of model programming are shown below.

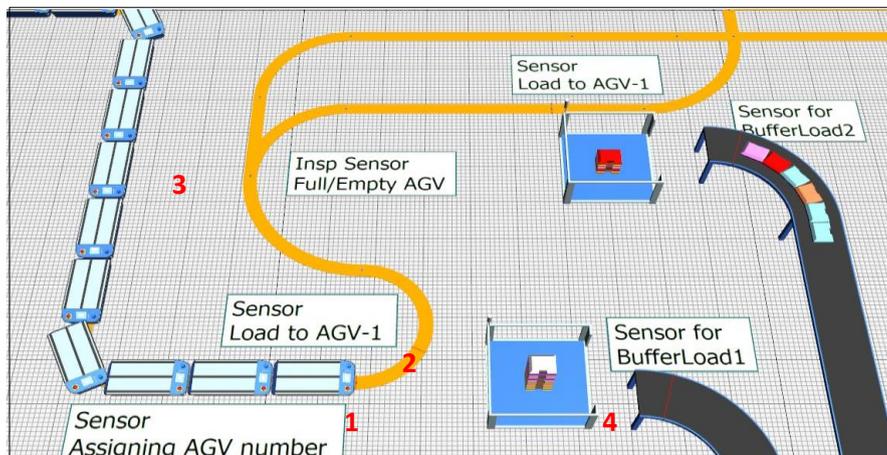


Figure 4: Part 1 of model programming in AGV system

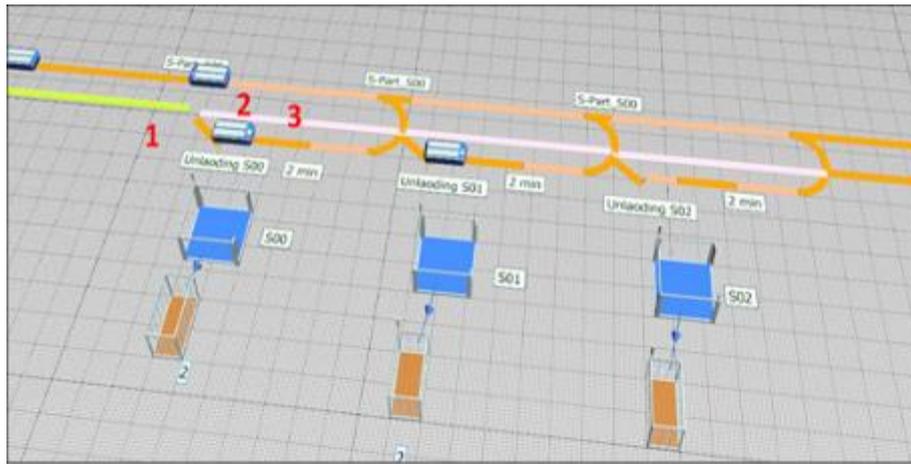


Figure 5: Part 2 of modal programming in AGV system

Validation for PHASE 4

The following step is to run a validation check when the AGV system layout design is finished. One of the crucial steps in evaluating the model's accuracy is validation. It makes sure that the created model accurately depicts the actual AGV system and that the produced outcome is comparable to or very close to the actual data supplied. The output from each station will be verified with the provided real data as part of the validation process. In addition, the model will compute the outcome after accounting for the different types of data distribution. The actual data and the output data from various distribution types were compared. We will select the candidate that best fits the actual data. Based on the data collection and analysis, it is demonstrated that the AGV model may utilise the Lognorm, Gamma, and Weibull types of distribution. Each of these distributions was entered into one of the AGV model's seven sources, and the output was calculated after the simulation was conducted. The output of the seven assembly lines for the AGV model is shown in Table 4 below, along with the actual data. The output totals for Lognorm, Gamma, and Weibull are 238, 236 and 236 respectively, according to Table 4 below, however, the output total for real data is just 209. Lognorm output is 14 % higher than the real output. Meanwhile, Gamma and Weibull are 13 % higher than Real output. There is no significant difference among them. As Gamma and Weibull have the same value, and the difference in the value is not more than 30, it is proved that the validation of the AGV model design is successful.

Table 4

Validation using AGV model and real data

Source Output	Lognorm	Gamma	Weibull	Real Output
Source_S0	21	37	34	17
Source_S1	20	12	17	55
Source_S2	36	51	46	50
Source_S3	42	8	16	8
Source_S4	45	54	48	30
Source_S5	47	50	49	40
Source_S6	27	24	26	9
Sum	238	236	236	209

AGV System Improvement

Problems Observed and Focus Point (Constraints)

The next action is to run the simulation for the AGV system model and analyse the issues when the validation process is finished. The AGV system model is depicted in Figure 6. According to the observation, the seven assembly lines are not too much obstructed or delayed.

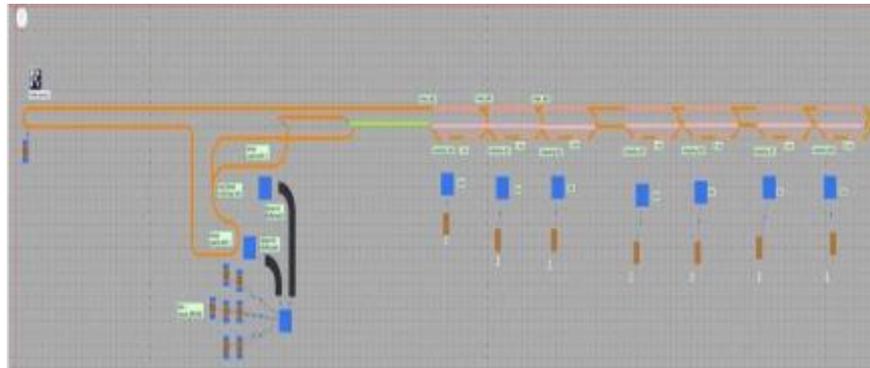


Figure 6: AGV system model

The loading station area has been identified as the primary issue. The loading station area's simulation output is displayed in Figure 7. The AGV is heavily obstructed along the route. This area becomes a bottleneck process, and it restricts the system's overall capacity or performance.

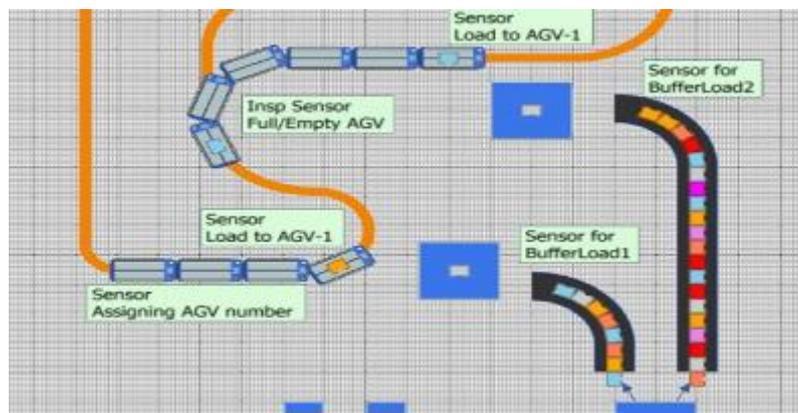


Figure 7: AGV system model loading station area

Blockage at Load Station 1: To load the part, the AGV is intended to travel to load stations 1 and 2. However, the area in front of load station 1 is heavily congested. There are two primary causes. There is only one track, which is the second reason, and a lengthy loading time of 16.17 minutes, which is the first. Due to this, the AGV cannot move to load station 2, thus it must wait until loading at load station 2 is complete.

Blockage at the junction of Load Station 2: The junction of Load Station 2 was the site of the second blockage issue. The AGV that has finished loading in station 1 is supposed to go directly to the forward track without stopping at the load station 2 track. The loaded AGV was forced to wait since it could not move through the junction due to the obstruction in load station 2.

Lastly, the blockage in load stations 1 and 2, also causes a blockage in the conveyor 1 and 2. With the issues described above, two proposals were made in response to the issues.

Proposal 1

The primary goal of Proposal 1 is to solve the issues that arise in the AGV system mode. The graphic simulation of the original and suggestion 1 for the AGV system model is shown in Tables 5 and 6 below, respectively. The main two objectives are reducing the blockage condition in the loading station area and minimizing the cost.

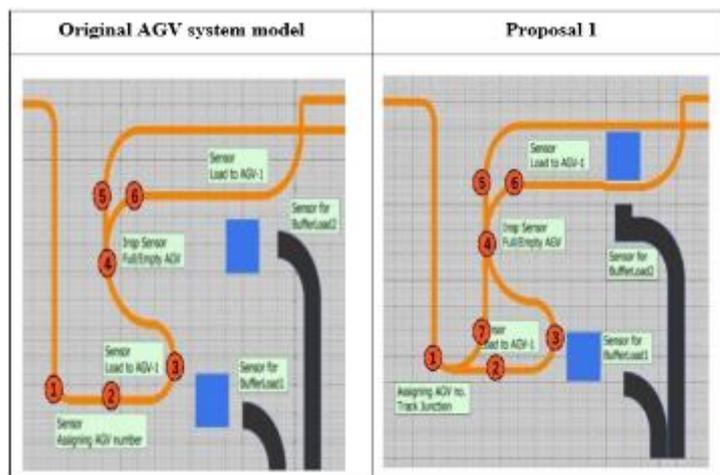
Table 5

Improvement made for Proposal 1

Objective to achieved	Improvement	Original	Proposal 1
Reducing the blockage condition	Reduce the Blockage in Loading Station 1	AGV going to loading stations 1 and 2 shares only 1 track	Add one junction track before Loading Station 1, so that the AGV can move to Loading Station 2 without needing to wait for Loading Station 1 to complete the loading.
Minimizing cost	AGV Quantity	14 AGV	Reduces to 10 AGV

Table 6

Graphic simulation of the original and proposal 1 for the AGV system model



Proposal 2

Proposal 2 focuses on improving the problems encountered in the AGV system mode. The objective of Proposal 2 is highlighted below. Tables 7 and 8 below show the improvement made for Proposal 2 and the graphic simulation of the original and Proposal 2 for the AGV system model. The main two objectives are reducing the blockage condition in the loading station area and increasing the delivery output rate.

Table 7
Improvement made for Proposal 2

Objective to achieved	Improvement	Original	Proposal 2
Reducing the blockage condition	Reduce the Blockage in Loading Station 1	AGV going to loading stations 1 and 2 shares only 1 track	Add one junction track before Loading Station 1, so that the AGV can move to Loading Station 2 without needing to wait for Loading Station 1 to complete the loading.
Increase delivery output rate	Add another loading station	2 loading station	3 loading station

Table 8
Simulation of the original and proposal 2 for the AGV system model

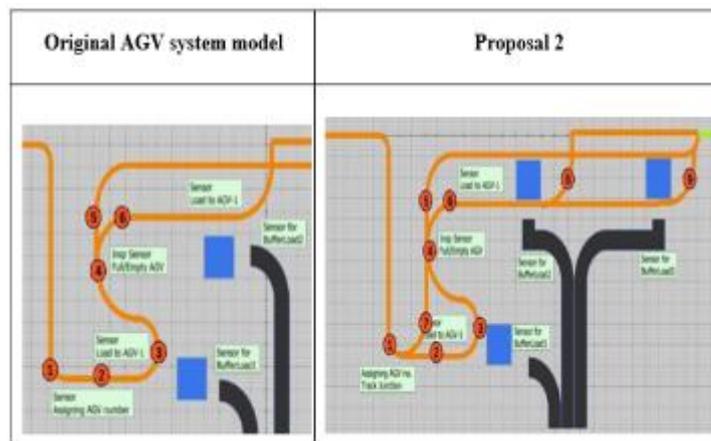


Table 9
Statistic result of the track system model (Original and Proposal 1)

Track	Working		Waiting		Blocked		No. Of Entry	
	Ori	P1	Ori	P1	Ori	P1	Ori	P1
Track 1	0.20%	0.19%	4.40%	56.06%	51.65%	0.00%	246	248
Track 2	0.24%	0.22%	2.44%	27.37%	53.57%	28.66%	246	142
Track 3	0.38%	0.29%	55.87%	55.96%	0.00%	0.00%	243	140
Track 4	0.41%	0.32%	54.78%	55.93%	1.05%	0.00%	242	139
Track 5	0.25%	0.19%	56.00%	56.06%	0.00%	0.00%	137	139
Track 6	0.15%	0.17%	50.72%	55.68%	5.38%	0.40%	104	106
Track 7	-	0.34%	-	55.91%	-	0.00%	-	106

Based on the Statistics result of Track for Proposal 1 from Table 9, can see that the working period at Track 1 to 5 is reduced compared to the original system. For Track 6 it was slightly increased but Track 7 which at Nil was now significantly up by 0.34%. The waiting period

increases significantly compared to the original system. Track 7 which was at Nil previously was now significantly up by 55.91%. Apart from that, the blocked period was reduced significantly as it was our primary goal to be improved. The number of entries also balanced to all tracks than the original system which kept zero entry at Track 7.

Table 10

Statistic result of the track system model (Original and Proposal 2)

Track	Working		Waiting		Blocked		No.Of Entry	
	Ori	P1	Ori	P1	Ori	P1	Ori	P1
Track 1	0.20%	0.24%	4.40%	56.01%	51.65%	0.00%	246	316
Track 2	0.24%	0.24%	2.44%	53.62%	53.57%	2.39%	246	106
Track 3	0.38%	0.22%	55.87%	56.03%	0.00%	0.00%	243	105
Track 4	0.41%	0.24%	54.78%	56.01%	1.05%	0.00%	242	104
Track 5	0.25%	0.14%	56.00%	56.11%	0.00%	0.00%	137	104
Track 6	0.15%	0.37%	50.72%	55.57%	5.38%	0.32%	104	210
Track 7	-	0.76%	-	55.49%	-	0.00%	-	210
Track 8	-	0.15%	-	56.10%	-	0.00%	-	121
Track 9	-	0.11%	-	56.14%	-	0.00%	-	86

Based on the Statistics result of Track for Proposal 2 from Table 10, we can see that the working period at some tracks increased, and some tracks decreased compared to the original system. But for Track 7,8 and 9 which previously had no data now have risen in significant percentage of the working period. The waiting period increases significantly compared to the original system. Tracks 7,8 and 9 which previously had no data now have risen in significant percentage of working period. Apart from that, the blocked period was reduced significantly as it was our primary goal to be improved. The number of entries also balanced to all tracks than the original system which kept zero entries at Tracks 7,8 and 9.

Based on the comparison of the Current system with both Proposal 1 and 2 from Table 11, it clearly shows that both proposals are efficient compared to the current original system. In terms of the working period, Proposal 1 is 3.20% and Proposal 2 is 2.87%.

Table 11

Statistic Result of the AGV system model

Transporter	Working			Waiting			Paused		
	Ori	P1	P2	Ori	P1	P2	Ori	P1	P2
AGV Quantity	14	10	14	14	10	14	14	10	14
	2.25%	3.20%	2.87%	55.81%	54.87%	55.19%	41.94%	41.94%	41.94%

Table 12

Statistic result for delivery output

Source Output	Original	Proposal 1	Proposal 2
	Actual	10 AGV	14 AGV
Source_S0	17	38	44
Source_S1	55	12	19
Source_S2	50	49	71
Source_S3	8	8	9
Source_S4	30	59	73
Source_S5	40	50	61
Source_S6	9	25	29
SUM	209	241	306

Both are significantly higher compared to the original which is 2.25%. In terms of waiting period, Proposal 1 is 54.87% and Proposal 2 is 55.19%. Both are significantly lower compared to the original which is 55.81%. The Paused period remained the same for Proposal 1.

Table 13

Cost analysis for current AGV model, proposal 1 and proposal 2

	Per unit	Current AGV Model	Proposal 1 Model	Proposal 2 Model
AGV Quantity		14	10	14
AGV Operating cost per year (RM) (Include electricity and maintenance cost)	7500	105000	75000	105000
AGV operating cost per month (RM)		8,750	6,250	8,750
AGV installation cost (RM) (For Track Programming cost)		0	1500	3000
Additional Loading Station (RM)		-	-	10000
Total Investment cost		-	RM1500	RM13000
Monthly Cost		RM8750	RM6250	RM8750

The goal of this study is to examine the AGV system's performance for the company and assess whether the current AGV system is adequate for it. The delivery output of the data provided by the company is revealed to be 209 based on the statistics results that are displayed. Table 12 shows results from proposals 1 and 2 241 and 306, respectively. This suggests that both options are adequate for the company's existing delivery rate needs. The company can be more confident in considering both proposals as both show promising output results compared to the actual one. These two ideas are put out to achieve various goals.

The first idea will be more appropriate if the organisation wants to increase delivery output minimally, but the monthly cost will be reduced. The company will just need to spend the least amount of money to modify the AGV track's programming in order to put this suggestion

into practice. However, as our plan lowers the operating cost as the number of AGVs decreases from 14 to only 10, as indicated in Table 4.10, the overall operating cost will decrease. For a business, cutting running costs can have several benefits. The possibility of higher profitability is one of the main benefits of cutting operating costs. The difference between revenue and costs increases as expenses fall, enabling bigger profit margins. A corporation might get a competitive edge in the market by having lower operating costs. A business can get more clients and expand its market share by providing goods and services at cheaper prices than rivals. A company's pricing strategy might be more flexible when operating costs are decreased. There are more options for pricing decisions based on market dynamics because it can decide to retain prices while raising profit margins or cut prices to increase market share. A business can increase its financial stability and resiliency by cutting operating costs. A business is better able to withstand downturns in the economy or unforeseen financial difficulties if expenses are reduced and profits are enhanced. Reducing operating expenses might free up money that can be used to fund growth projects, R&D, new technologies, or market expansion. This can support sustained growth and help a business keep one step ahead of its rivals. The situation of a company's cash flow can be improved by cutting operating costs. Less spending means more money for dividends, debt reduction, reinvestment, and other tactical purposes. Employee morale and job security can increase when a company successfully cuts operating expenses without sacrificing employee well-being. This may result in more productivity, a more positive workplace climate, and improved employee retention rates.

The second option will be more appropriate if the company's goal is to increase delivery output drastically. Based on Table 4.9, it can be shown that the delivery output significantly increased when Proposal 2 was implemented, going from 209 to 306. A business can fulfil customer orders more swiftly and effectively by increasing delivery output. Customers may be more satisfied as a result of receiving their goods or services more quickly. Companies with a clear competitive advantage in the market are those who can offer goods or services faster and more reliably than their rivals. Increased delivery output can aid a business in developing a reputation for dependability and effectiveness, drawing in more clients and possibly gaining a larger portion of the market. Faster delivery times may result in higher revenue and sales. Customers are more likely to select a business that delivers prompt delivery, particularly in sectors where time is a crucial consideration. This may boost recurring business and promote recommendations from friends and family. The supply chain needs to be streamlined and optimized often to increase delivery output. This may result in more effective operations overall, shorter lead times, enhanced supplier cooperation, and better inventory management. A corporation may be able to obtain economies of scale and lower expenses through increasing delivery output. A corporation may be able to save money by negotiating better prices with suppliers, lowering transportation expenses, or streamlining manufacturing procedures by producing and delivering more items or services in bulk. Process upgrades and improved operational effectiveness are frequently required while concentrating on raising delivery production. It promotes businesses to find and remove bottlenecks, reorganize workflows, automate procedures, and boost productivity. The company's complete operations, not simply the delivery services, can profit from these changes. Fast and dependable delivery can help build a brand's reputation. Customers relate professionalism, dependability, and expertise to effective delivery. A positive brand reputation can draw in new clients and increase the loyalty of current ones. Expanding into new markets and

expanding geographically can both be facilitated by increasing delivery output. It makes it possible for a business to provide goods or services to a bigger consumer base, thus expanding its reach and opening new growth options. Due to the inclusion of an additional track and station and the associated programming costs, proposal 2 will cost more, at RM13,000, although the corporation may still choose it in the long run. In a nutshell, both proposal 1 and 2 has its uniqueness and constraints.

Conclusion

In conclusion, the simulation approach employed in this project helped to achieve the project's goals and objectives, as well as to structure the report and every step of the procedure. Simulation modelling for the AGV system was created using the company's most recent data, and after extensive testing, enhancements were proposed. Because there was sufficient information on the inputs to build an almost perfect replica of the real production line, there were often no significant challenges when building the model in the Tecnomatix plant simulation model. Building the model to reflect the actual flow of AGVs and processing stations has been the most difficult hurdle.

Finally, a successful AGV system model has been created with outputs that are almost identical to the actual ones. The loading station region is the primary issue in the entire AGV system, with several AGV blockages along the track, according to the simulation model for the AGV system. To compare the improvement to the original model, two proposals were created. The results as they are presented above indicate that both plans are sufficient for the company's existing delivery rate requirements. Since a business won't adopt two plans at once in the real world, doing so will result in a loss of money and time. The business can therefore put into practice whichever of these two ideas best suits their current circumstances. This project demonstrated how a simulation model can be used to not only predict production parameters but also to identify organizational and operational changes that must be made to successfully implement an improved future state simulation. It also demonstrated how the Sim Talk programming language can be used to create a real-time simulation model that is most comprehensive and meets the needs of the user.

Besides, from a sustainability point of view, simulation provides an efficient, cost-effective, and environmentally friendly way to develop projects because they remain in a virtual environment until they are built in the real world (Rahman et al. 2022). This helps to avoid wasting resources while also improving the environmental footprint.

Future Recommendation

Total average WIP is another in-depth analysis that can be done to optimise layouts. Here, factors like low yield rates and machine breakdown can be researched. The creation of a system that might assist tasks prompting best practices and assess choices for the deployment of machines and devices is advised for simulation. One of the best ways to reduce production time and boost productivity in small- to medium-sized businesses is to leverage technology, but doing so will need an investment.

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