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Continuous Improvement of Productivity with Applying Lean Principles in Designing and Simulating: A Case Study

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ABSTRACT

Increased productivity could be a prerequisite for every business looking to compete. The lean principle is a useful and popular method to achieve this. This paper presents a case study on the successful implementation of lean principles in the shoe manufacturing process. The goal of this article is to achieve continuous production improvement and reach line equilibrium. Limited manufacturing resources are effectively integrated with lean tools in a suggested real-time bottleneck control strategy to mitigate short-term production constraints and achieve continuous production improvements. This is done through the use of a novel 4.0 management approach that makes use of Blockchain (QR code), a real-time production reporting system (Realtime Production), and the organization and movement of goods. The case study demonstrates promising results in improving productivity in a shoe factory. This approach could also be considered for implementation in other production fields such as electronic assembly lines, garment lines, and furniture assembly lines.

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1. Introduction

In the last few years, information technology has gained enormous popularity in management and technical operations. A novel 4.0 management approach using Blockchain (QR code), 4.0 supply system (Smart Supermarket, self-propelled AGV), and real-time production reporting system (Realtime Production) are crucial to achieving anticipated efficiency. The production system's WIP (work-in-process) drives up inventory costs and system cycle times, which result in greater costs and less responsiveness, respectively. Hence, the goal of WIP control is to minimize production variations and maintain minimal WIP while maintaining the required throughput. It is noted that to achieve continuous product improvement and an efficiently balanced-line status, these bottleneck control policies concentrate on steady-state production control while ignoring real-time bottleneck control [1]. To meet varied performance goals, a control method that can offer short-term real-time control for industrial systems with unreliable equipment and finite internal buffers is required. Real-time data analysis can reveal opportunities or benefits that would otherwise go unnoticed during a long-term evaluation. To demonstrate procedures and decision-making, simulations are defined as activities that mirror the realities of a clinical environment [2]. A simulation model that may verify a production line balancing issue in a particular instance that relates to the footwear business, where they must address specific requests from the clients regarding the footwear industry. To assess and confirm balancing activities, such as the addition or removal of machines from the production line or changes to orders, the simulation model must be able to replicate the operation of the production line [3]. Real-time decisions based on the detection and alleviation of bottlenecks are preferred in actual circumstances. Unfortunately, both analytical and simulation techniques have their limitations when it comes to performing real-time bottleneck control, which results in missed opportunities for potential production losses. To monitor system performance in real-time and to achieve sustainable production benefits based on continuous product improvement, a real-time bottleneck control method is developed in this work employing live measurable data such as production line blockage and starvation information. Initial buffer modification is a practical technique for short-term bottleneck mitigation that is developed to constantly enhance system performance toward balanced-line production conditions [4]. Real-time production control system for a manufacturing line with multiple bottlenecks. The system is built on Lean manufacturing principles and a fuzzy logic controller. The authors analyze the suggested system using a simulation model and show that it can greatly boost productivity and reduce cycle time in a manufacturing line with many bottlenecks [5], [6]. An assembly line for shoe production is utilized as an industry case study to show the benefits of this method.

2. Materials and methods

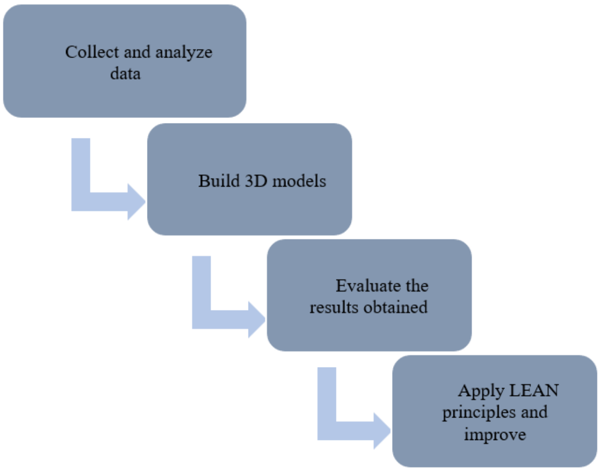


Figure 1. *Methodology steps used in this paper*

Step 1: Gather Information.

The input materials for the factory include plastic particles, rubber, paper, glue, and items for storage. The company produces plastic and rubber soles. These materials are processed and mixed before being pressed into rubber. The semi-finished goods (Fig. 2) are then returned to the warehouse. Next, the semi-finished product is moved to the stamping step, where the base is shaped according to the design and order request at the cutting stage. Semi-finished items are consolidated and stored at the cutting stage's warehouse. These items are then transferred to the main plant and stored until the sole is ready to be made after all phases at the shoe sole factory are completed. The semi-finished items are then moved to the production area, where they undergo processes such as grinding, molding, gluing, and stitching. After processing, the item codes are moved to the sewing stage storage area. Once the production code is ready, the semi-finished products will continue to the completion stage, where they are assembled, combining the base with supplies including straps, wires, and decorations to create the final product. The final product is then placed in finished product storage. If customers request multiple product sizes in the same box, the products will be concentrated in the complex packaging area to categorize and separate them according to customer requirements. Currently, the production process is divided between 2 factories: The Shoe Sole Factory and the Complete Factory. There will be more semi-finished products in the 2 factories, which will result in costs for storage, transportation, labor, and possible damage in transit.

Step 2: Design and Simulation

Based on the data collected, detailed 2D CAD drawings will be created to define workspace dimensions and configurations. These drawings will be used to develop a 3D factory model in SketchUp, optimizing layout and equipment placement according to Lean principles. After that, a virtual factory model will be created in FlexSim software to simulate production processes (Fig. 3) and generate performance metrics, including production output, inventory levels, and resource utilization.

Step 3: Performance Evaluation

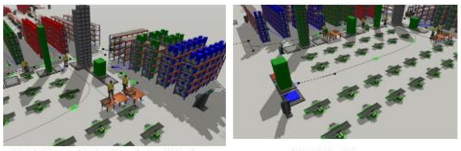
The simulation results will be studied to evaluate the effects of suggested enhancements on key performance indicators (KPIs) like storage use, inventory levels, productivity, and work-in-progress (WIP). Resource needs, including AGV and smart supermarket usage, will be assessed to optimize system setup and allocation.

Step 4: Lean Implementation

We will apply lean principles to optimize storage and production processes. The storage areas will be designed to minimize lead times and maximize space utilization, taking into account factors such as product type, customer requirements, and inventory turnover rates. We will implement a systematic approach to inventory management, including the use of two-bin systems and regular inventory audits. We will closely monitor and control work in progress (WIP) levels to prevent bottlenecks and optimize production flow.

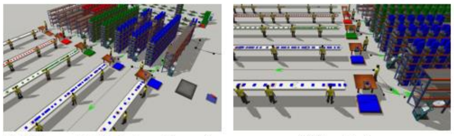
Figure 2. *Semi-finished products warehouse*

Loading and unloading, searching, transporting, and managing inventory does not contribute to creating value for the product. Variability is a crucial factor to consider when assessing a process's performance. A bottleneck machine's low variability can result in high production variability [7]. There is a situation of "bottlenecks" in many stages, leading to too much inventory and reducing the productivity of the whole factory. Generates more costs: hiring workers, maintaining transport machinery, managing warehouses. The traditional warehousing operation demonstrates that numerous processes require employees to make decisions and take actions that can result in human error and lower the warehouse's operational performance [8].



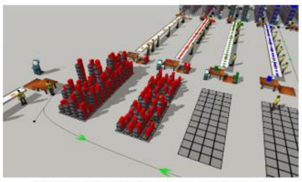
WIP Semi-finished products Grinding room

WIP Grinding room



WIP The semi-finished store of shoe soles

WIP on the line



BTP The end of the line Prepares the shoe soles

Figure 3. *Real-time production simulations in areas*

The following matters are defensible: There is more than the production capacity in the semi-finished area. Each region's WIP inventory is very high. The product has a lengthy inventory retention period on the system. The following solutions are applicable: Prioritize or accelerate production for each product type. Rearrange the production layout to reduce the work-in-process (WIP) inventory in the line. This is demonstrated through the results of discrete event simulation and visual design in the following section.

3. Results and Discussion

3.1. Modeling of lean production systems

Design and combine 2 factories into 1, with the 1st floor being Shoe sole Factory and the 2nd floor being Complete Factory. Production plan: includes types of product codes, quantities, and delivery date information, ... Following that, the product codes are specified and assigned to a type of container of semi-finished products corresponding to the order of priority. Includes 3 color types of containers as shown in the Figure 4: Red - For product codes with urgent production schedules, priority should be given to meet orders. Orange - Corresponding to the product code with average production progress, the priority level after the red box. Blue - Corresponding to the product code with normal production progress. Can produce after finishing the above 2 colors.

Figure 4. *Color-graded containers in semi-finished areas*

In addition, all containers are assigned a QR code that includes information: product code, quantity, stages passed, supplies, necessary materials, the process of creating products, etc. Scanning product codes at the beginning and end of lines and stages. After that, the information will be sent to the management system in real-time to help capture the productivity of the line and have a timely solution when there is a problem with productivity.

3.2. Applying 4.0 to factory management

Real-time production monitoring:

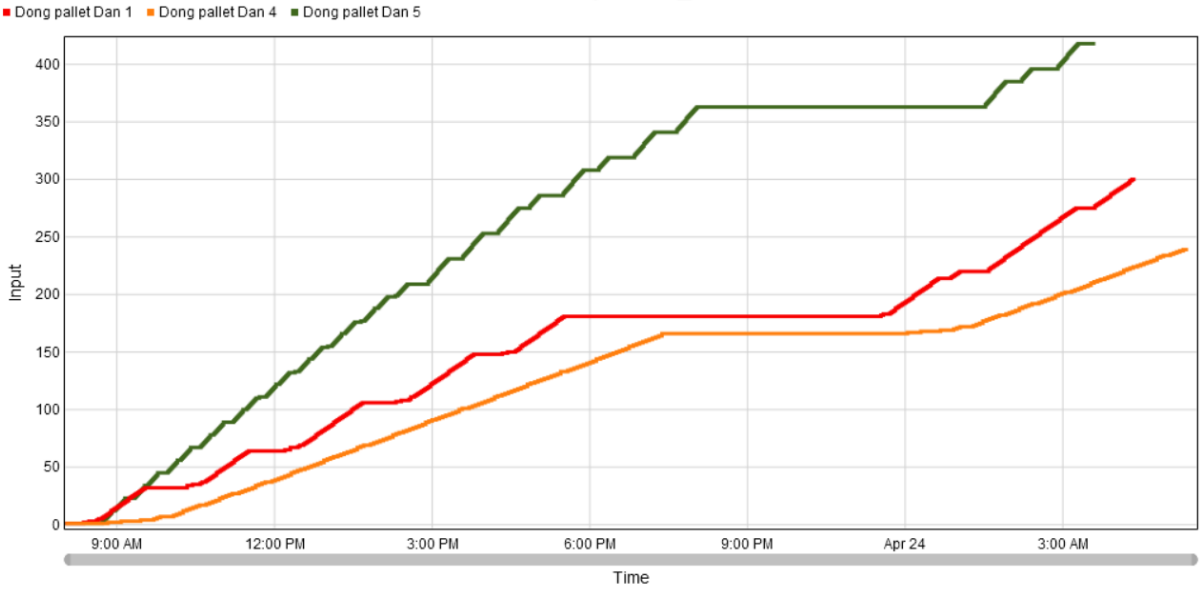


Figure 5. *Production increase with control*

Technology is required to monitor the manufacturing system's status and acquire data at any time [9]. Real-time monitoring of a manufacturing process enables production performance analysis and exception diagnostics by mining the collected data and corresponding knowledge. This allows for ongoing improvement of a manufacturing process performance [10]. A Discrete Event Simulation model using Flexsim of the assembly line was developed and used to identify areas for improvement. Lean techniques such as Kaizen and Poka-Yoke were then applied to address these areas. The proposed improvements resulted in a significant increase in throughput [11]. This study proposes a real-time production control system for a manufacturing line with multiple bottlenecks. The system is based on a combination of Lean manufacturing principles and a fuzzy logic controller. The authors evaluate the proposed system using a simulation model and show that it can significantly improve productivity and reduce cycle time [12]. Using Lean manufacturing to improve the bottleneck process in a manufacturing company and factors that influence work-in-process (WIP) levels in a Lean manufacturing environment [13]. The proposed improvements resulted in an increase in productivity and a significant reduction in cycle time [14]. By arranging scanners at the end of the production line, each product has its own QR code, when the product reaches the end of the line it will be scanned and the output will be updated directly on the system quickly, fastest, and most accurately. In case there is an abnormal change in output, lack of output, or unproductive goods, overproduction will be controlled (Fig. 5).

Smart Supermarket System – Auto Supermarket (Fig. 6 and Fig. 7):

At the storage location. Store input and output information of each item code based on which the warehouse manager can capture and thoroughly manage the current inventory. The structure of the pallet warehouse includes a racking system with a multi-story structure, each shelf will be divided into many small storage cells and assigned a QR code that stores shelf information, cell location, and the type of item code stored on the pallet.

Figure 6. *Auto Supermarket*

For warehouse export: The system will automatically locate and find the location of the pallet with the required item code quickly, through the stored data when entering the warehouse and scanning the QR code on the location storage box on the shelf. Avoid getting the wrong product code, or lack of quantity, save time searching, and save operating energy.

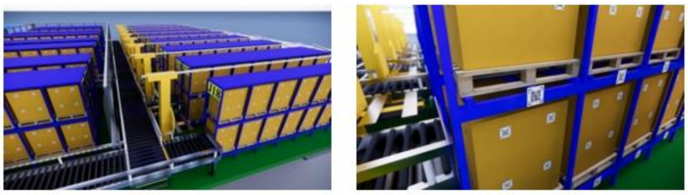


Figure 7. *Auto Supermarket with QR code*

Smart transportation system – AGV (Fig. 8):

During this process, AGV will scan the QR code on the containers and send information including shipping time, type of item code, quantity, and storage location in the semi-finished warehouse to the management and storage system in real-time. For warehouse export operation: When there is a production request, AGV will be called out to get the correct item code, quantity, and position of cells on the shelf that have been saved after the warehousing process. Take the pallet to the production line and continue to send relevant information about the item code to the management system.

Figure 8. *AGV system*

Blockchain-based production management – Label – Item List:

Instead of having to use the usual tags and notes on products that we often encounter. Goods will be identified everywhere in the production process, and after passing each station, stage, area, etc., that information will be stored again. Distribution of materials and semi-finished products to production stages will be easier. Just manage digital data, and the computer will completely do it quickly and accurately. Management by digital data, and computers will completely do it quickly and accurately, and the distribution of manufactured goods according to the plan of "Smart warehouse system - Auto Supermarket" is fully exploited.

To demonstrate that the improvement works, especially the operational efficiency of Auto-supermarket by simulation of 3 types with different cycle times. After that, we will evaluate the above improvement by 2 indicators which are the waiting time (Staytime) and the number of queues (WIP) in the Auto-supermarket. We will simulate both models with the same cycle time databases which were changed continuously. With a cycle time minimum of 4 seconds and a cycle time maximum of 12 seconds, we utilize the Randbetween(4,12) function in Excel applied to each line to obtain integer values for the cycle times.

Cycle time (s)			
No.	**Type1**	**Type2**	**Type3**
1	10.0	7.0	10.0
2	6.0	8.0	10.0
3	4.0	12.0	9.0
4	5.0	4.0	9.0
5	11.0	10.0	4.0
…			
96	6.0	4.0	12.0
97	5.0	6.0	8.0
98	6.0	8.0	5.0
99	11.0	11.0	4.0
100	5.0	6.0	9.0

100 samples

Simulate with the database in two model system:

Since we cannot directly import the above data into the model, we need to change the cycle time property by converting them to data sets in the form of conveyor speeds corresponding to each type. To adjust the conveyor speed according to the product's CT, we divide the conveyor belt into CT cells with a size of about 300mm, the CT cell contains 1 pair of products. The conveyor speed will be calculated by:

$$Conveyor\ belt\ speed\left(\frac{mm}{s}\right)=\frac{300}{Maximum\ take\ time} \tag{1}$$

For example, the Cycle Time shoe code is 4s. Then conveyor speed = $\frac{300}{4}$ = 75 (mm/s). That way we will have the conveyor speed data set corresponding to the above cycle time as shown in the table below:

Conveyor speed (mm/s)			
No.	**Type1**	**Type2**	**Type3**
1	30	43	30
2	50	38	30
3	75	25	33
4	60	75	33
5	27	30	75
…			
96	50	75	25
97	60	50	38
98	50	38	60
99	27	27	75
100	60	50	33

100 samples

We will obtain two result data sets, which are STAYTIME (total waiting time) and WIP (number of boxes waiting) in Auto-Supermarket, corresponding to 100 samples tested consecutively on both models. Show the link between the independent factors (Types' cycle times) and the dependent variables (Staytime and WIP) using a scatter graphic (Fig. 9). Overall, we can find that the total waiting time for the semi-finished products in the Auto-supermarket after the improvement is much lower than before.

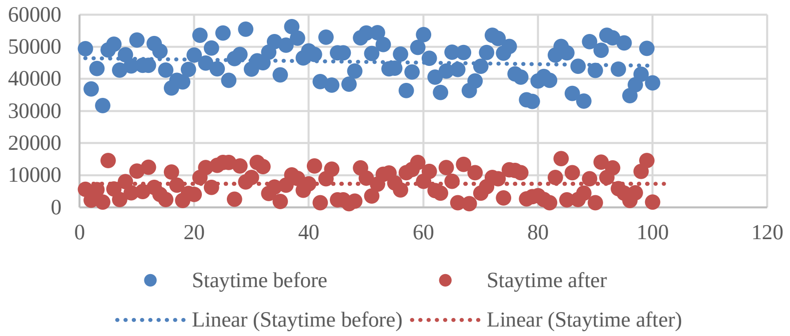


Figure 9. *The scatter chart of stay time's change*

Now we analyze and evaluate the distribution and reliability of the cycle time data leading to the change in the waiting time of the pre-improved system with 95% confidence.

Table 1. *Stay time's Regression Statistical Results Before Improvement*

STAYTIME BEFORE	
Regression Statistics	
Multiple R	0.955
R Square	0.912
Adjusted R Square	0.910
Standard Error	1775.290
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3146385034	1048795011	332.776	0.000
Residual	96	302558748.7	3151653.632		
Total	99	3448943782			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*

Intercept	15849.557	1022.421	15.502	0.000	13820.066	17879.046	13820.066	17879.046
Type1	1564.437	66.312	23.592	0.000	1432.809	1696.065	1432.809	1696.065
Type2	1471.401	70.742	20.800	0.000	1330.979	1611.823	1330.979	1611.823
Type3	571.800	64.372	8.883	0.000	444.022	699.578	444.022	699.578

Since the p-values of the variables are much smaller than 0.05, the multiple regression model has statistical significance for the variables (Table 1). Continue to review the model after improving the system as shown in the Table 2.

Table 2. *Stay time's Regression Statistical Results After Improvement*

STAYTIME AFTER

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.909
R Square	0.827
Adjusted R Square	0.821
Standard Error	1772.746
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1438191245	479397081.7	152.547	0.000
Residual	96	301692231.3	3142627.409		
Total	99	1739883477			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5460.497	1020.956	5.348	0.000	3433.915	7487.079	3433.915	7487.079
Type1	878.108	66.217	13.261	0.000	746.668	1009.547	746.668	1009.547
Type2	308.319	70.641	4.365	0.000	168.098	448.539	168.098	448.539
Type3	-932.881	64.280	-14.513	0.000	-1060.475	-805.286	-1060.475	-805.286

Since the p-values of the variables are much smaller than 0.05, the multiple regression model has statistical significance for the variables. Similarly, we will analyze and evaluate the distribution and reliability of cycle time data leading to the change in the number of queues (WIP) on the Auto-supermarket system before and after the improvement with 95% confidence. This is shown in the Figure 10.

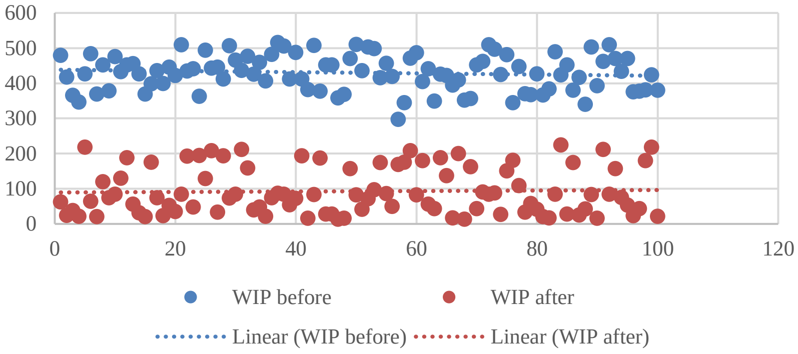


Figure 10. *The scatter chart of WIP's change.*

In general, we can see that the total amount of semi-finished products waiting at the Auto-Supermarket after improvement is much lower than before.

Table 3. *WIP's Regression Statistical Results Before Improvement*

WIP BEFORE

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.952
R Square	0.906
Adjusted R Square	0.903
Standard Error	15.632
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	225839.045	75279.682	308.048	0.000
Residual	96	23460.142	244.376		
Total	99	249299.187			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	212.912	9.003	23.649	0.000	195.041	230.782	195.040	230.782
Type1	16.908	0.584	28.957	0.000	15.749	18.068	15.749	18.068
Type2	2.650	0.623	4.254	0.000	1.414	3.887	1.414	3.887
Type3	6.727	0.567	11.868	0.000	5.602	7.852	5.602	7.852

Since the p-values of the variables are much smaller than 0.05, the multiple regression model has statistical significance for the variables (Table 3).

Table 4. *WIP's Regression Statistical Results After Improvement*

WIP AFTER

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.931
R Square	0.867
Adjusted R Square	0.864
Standard Error	24.286
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	371163.085	123721.028	209.772	0.000
Residual	96	56619.545	589.787		
Total	99	427782.630			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	158.196	13.986	11.311	0.000	130.433	185.959	130.433	185.959
Type1	8.778	0.907	9.677	0.000	6.977	10.579	6.977	10.579
Type2	2.755	0.968	2.846	0.005	0.834	4.675	0.834	4.675
Type3	-19.052	0.881	-21.635	0.000	-20.800	-17.304	-20.800	-17.304

Since the p-values of the variables are much smaller than 0.05, the multiple regression model has statistical significance for the variables (Table 4).

We can see a separate effect of each type on the results. Most of them are statistically significant for the model. Based on the p-value from the ANOVA analysis of the post-improvement results, it can be concluded that all three types have an impact on the regression model, with types 1 and 3 having the greatest impact.

The principal source of the difficulty in the process of supplying items to the production ends of the “Smart Warehouse System - Auto Supermarket” is standstill on the conveyor belt to the production heads. Recognizing the necessity of scheduling the delivery of goods, we undertake a leading survey of a passing demand in terms of numbers and time with lip contact as follows: When does the first line come out? With one pallet holding ten boxes corresponding to 360 pairings and the CT of the associated code, that is, the pass's manufacturing rhythm, we may calculate the corresponding time.

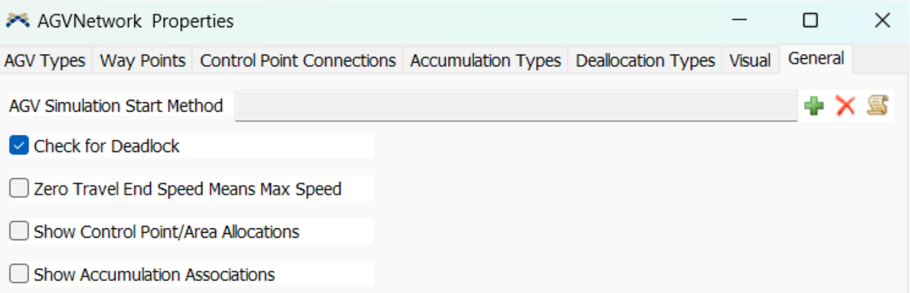
$$\text{Top grant time passes} = 360 * CT\ (s) \tag{2}$$

The number to supply each pass depends on the actual survey of the conveyor and the area for the top pass, we will plan to get the goods in the right quantity that the request is required.

The death point in the direction of AGV:

In the process of setting the direction for AGV, there will be times when the AGV is duplicated during the transportation process, so we need to check on the simulation to predict the situation that occurs.

Predict Deadlock points (Fig. 11) or predict the exact moment a collision will occur by checking, providing a specific, accurate, and timely change. Because the ultimate goal is to ensure the continuous operation of the system and maintain the maximum capacity of Factory 4.0.


AGVNetwork Properties

AGV Simulation Start Method

☑ Check for Deadlock

☐ Zero Travel End Speed Means Max Speed

☐ Show Control Point/Area Allocations

☐ Show Accumulation Associations

Figure 11. *Check deadlock - Check the collision of AGV*

4. Conclusion

A novel 4.0 management approach is proposed that uses Blockchain (QR code), a 4.0 supply system (Smart Supermarket, self-propelled AGV), and a real-time production reporting system (Realtime Production) to efficiently utilize finite manufacturing resources and mitigate short-term production constraints while achieving continuous production improvements. The Smart Warehouse System - Auto Supermarket and automatic AGVs are used in the production process to efficiently arrange and move items. Color grading of semi-finished containers can help to increase continuity, maintain and enhance production schedules, and ensure on-time deliveries. In general, real-time monitoring of manufacturing processes allows for production performance analysis and exception diagnosis by mining data and discovering relevant information. This enables ongoing improvement of manufacturing performance.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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