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Simulation and Evaluation of the Mattress Manufacturing Process Design Model

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ABSTRACT
In this paper, the design model of the mattress manufacturing process will be simulated and evaluated using Tecnomatix Plant Simulation software.Various SKU distribution control scenarios are tested to determine line balance.In addition, the sensitivity analysis of design parameters such as conveyor speed, lifter speed, as well as SKU loading time, etc. affecting the line balance was also examined. The simulation results showed that the Tecnomatix Plant Simulation software could beeffectively used for achievingoptimal parameters of the design systemas well as the SKU distribution control scheme.

General Terms
Simulation modelling.

Keywords
Discrete event simulation, modelling, production operations.

1. INTRODUCTION

Manufacturing is the process of turning raw materials or semi-finished products into finished products.For mattress manufacturing, semi-finished products called SKUs are gathered at a loading station and distributed to assembly stations. Here, workers assemble the SKUs to form the finished product.As required, assembly stations assemble SKUs with different product codes. The loading station must issue the SKUs to the assembly stations on demand in advance to achieve goals such as the number of products made in a shift, the balance between the stations, etc.To test control ideas as well as evaluate system design parameters, simulation tools are a good solution.

Simulation has been a widely used toolfor manufacturing system design and analysis for more thanmany years. It has proven to be one of the most flexible and useful analysis tools in the manufacturingsystem design and operation areas [1]. Author of the paper concluded that the use of simulation will continue to growand expand into new areas as computational powercontinues to increase and simulation software toolscontinue to simplify the modeling, execution, andanalysis functions associated with simulation projects.Especially, in the context of the 4th Industrial revolution, digitalization of manufacturing has shaped simulation in thedesign and operation of manufacturing systems [2].

In this paper, the author introduces an application of the Tecnomatix Plant Simulation softwarefortesting control strategies for distributing SKUs to assembly stations so that OEE requirements are metin the mattress factory. In addition, the system design parameters are also evaluated by sensitivity analysis.

The remaining paper is organized as follows: Section 2 synthesizes the results of using Tecnomatix Plant Simulation software in simulation of production activities. Section 3 describes the mattress manufacturing process, the deliverymethods for semi-finished products (SKUs) to the assembly stations. Section 4 shows the obtained results and Section 5 concludes this paper.

2. LITERATURE REVIEW

Tecnomatix Plant Simulation software is developed by Siemens for providing discrete event simulation and statistical analysis capabilities to optimize material handling, logistics, machine utilization, and labor requirements [3], [4].This section presents the applications of this tool in simulation studies, optimization of production systems.

In the paper [5], authors used Tecnomatix Plant Simulation software to build the simulation model of the production line. The results of the simulation with initial parameters show that the existing model of production doesnot allow a profit because the lines are not balanced and therefore there are unnecessary costs.With the help of the combination of the linebalancing and discrete event simulation model, productivityis increased from 76 initially to 302 manufactured products atthe end. Therefore, the productivity is raised by almost 400%.

The paper [6] presented a general discrete event simulation model developed in PlantSimulation software that controls AGVs in robotic assembly systems.Simulation model contains layout configurator and maintenance planning modules.These modules are used to solve simple assembly scheduling problems, the control algorithmsof the AGVs, and the complete material flow including themotions of the robots, AGVs and workpieces in ageneral manner.

The operation management in a warehouse can be also simulated in Tecnomatix Plant Simulation. In the article [7], authors selected this tool to create a warehouse operation model andmanipulate the number of trucks and workers to achieve the company’s target without real process interruption.

In Industry 4.0 era, the concepts such as digital twin and virtual factory are gradually applied in the field of manufacturing. Simulation tools become more and more important. Authors [8] used Tecnomatix Plant Simulation software to verify and compare the logistics solutions for an automatic plant factory.While the authors in article [9] presented a technological concept focused on continuousoptimization of production processes, efficient use of resourcesthrough the formation of advanced production strategies,planning and logistics.

3. PROBLEM DESCRIPTION

3.1 Mattress manufacturing process

The mattress manufacturing process is illustrated in Fig. 1. The layout is designed according to the current state of the factory.Mechanical parameters are omitted in this paper.

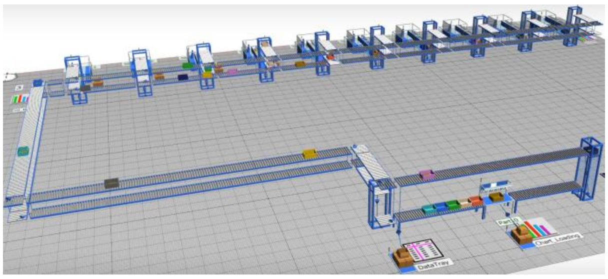

Fig 1: Mattress manufacturing process

This process is divided into 3 stages:

- Feeding semi-finished products (SKUs) into the trays at loading station.
- Transporting SKUs to assembly stations.
- Assembling the SKUs to form the finished product.

There are a total of 10 assembly stations to produce item codes (SKUs) as shown in Table 1.

Table 1.Mattress assembly time

No	Item code	Size	Assembly time
1	C1	S	4’02
		D	5’18
2	C2	S	5’28
		D	6’07
3	H03	S	4’02
		D	5’07
4	Zero VB	S	4’14
		SD	5’07
5	Zero ligh3	S	3’35
		SD	4’20
6	COMFOR	S	5’50
		D	6’20
7	U1	S	3’20
		SD	4’30
8	T1-CR	D	7’00
		Q	8’35

Strategies for distributing SKUs at the loading station to the assembly stations are presented in section 3.2.The objective is to find a control strategy that satisfies a given OEE for production assemblies SKU.

3.2 Control scenarios

Thereare 3 scenarios used to control the delivery of trays to the assembly stationsstudied in this paper.

3.2.1. Scenario 1 - Delivery of trays

Trays are allocated to assembly stations. At the loading station, SKUs are allocated to the specified trays and will be transported to the respective stations.The assembly station that finished, return the empty tray first, will be allocated the SKU first at the loading station. In this way, the faster assembly station will be allocated more SKUs, which will maximize the capacity (OEE) of that station.

Because stations have a fixed buffer of 2 to accommodate 2 trays, and 1 tray on the lifter and only provide a maximum of 3 trays for a station, so there will be no transmission jam caused by the station when that station fails.

3.2.2. Scenario 2 - Delivery of SKU according to OEE

At the loading station, SKUs are allocated to the trays in order: the station with the smallest OEE and the smallest buffer (i.e., the station with the freest time) is allocated the SKU first. In this way, stations with the same assembly time tend to be evenly distributed OEE.

Since stations can only hold up to 3 trays, this distribution solution must know how many trays are currently allocated to that station to avoid the case that more trays are allocated than the station can handle.

3.2.3. Scenario 3 - Delivery of SKU according to loading time

Equilibrium equation:

$$t^i_{loading} + t^i_{moving} = t^i_{processing}\left(1 + N^i\right)$$

Where: $t^i_{loading}$:loading time for station *i*

t^i_{moving} :moving time to station *i*

$t^i_{processing}$:processing time at station *i*

N^i: number of SKUs are allocated to station *i* that moving on conveyor

The station with the smaller $t^i_{loading}$, means the more urgent it is, the SKU will be issued first. After each SKU allocation to a station, the above equation is recalculated.The shorter the SKU's processing time, the greater the number of SKUs on the conveyor.

4. SIMULATION RESULTS

4.1 Simulation parameters

The parameter settings for simulation are shown in Table 2.

Table 2.Simulation parameter settings

Parameters	Value	Unit
Conveyor speed	0.4	m/s
Lifter speed	0.3	m/s
SKU loading time	30	second
Number of feed trays	30	tray
Simulation time	8	hour

4.2 Results and discussion

The following are the comparison results of 3 control solutions corresponding to several combinations of SKUs.

4.2.1. Combination 1: produce products with the same processing time and less than 5 minutes

Select product code zero – light3 – S with processing time 3'35. This is a product code belonging to the group of regularly produced products.

Number of products produced and OEE of each station are given in Table 3. Distribution of OEE over 10 stations of 3 control solutions is shown in Fig.2, Fig.3 and Fig.4.

Table 3.Number of products and OEE of each station

	Scenario 1	Scenario 2	Scenario 3
Station 1	99	94	89
Station 2	99	94	89
Station 3	97	94	89
Station 4	95	94	89
Station 5	95	94	89
Station 6	95	94	89
Station 7	95	94	99
Station 8	88	94	101
Station 9	88	94	102
Station 10	88	94	103
Total	939	940	939
OEE	90.23	89.98	90.06

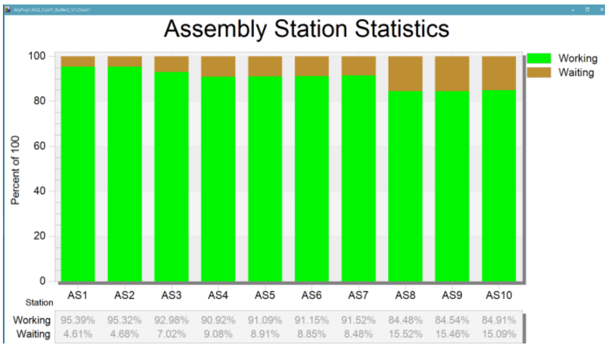

Fig2:OEE distribution over 10 stations of scenario 1

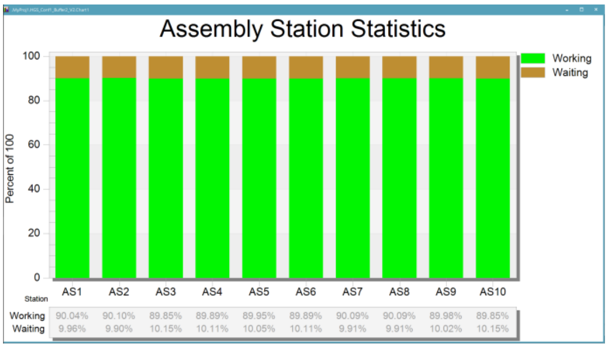

Fig3:OEE distribution over 10 stations of scenario2

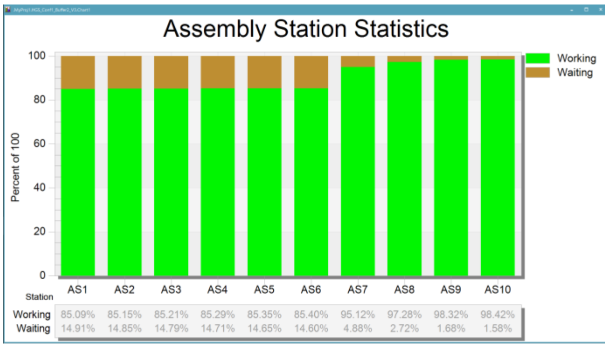

Fig4:OEE distribution over 10 stations of scenario3

4.2.2. Combination 2: produce products with the same processing time and more than 5 minutes

Select productcode zero – light3 – S with processing time 5'07.

Number of products produced and OEE of each station are given in Table 4. Distribution of OEE over 10 stations of 3 control solutions is shown in Fig.5, Fig.6 and Fig.7.

Table 4.Number of products and OEE of each station

	Scenario 1	Scenario 2	Scenario 3
Station 1	76	76	76
Station 2	76	76	76
Station 3	77	77	76
Station 4	77	77	77
Station 5	77	77	77
Station 6	77	77	77
Station 7	77	77	77
Station 8	77	77	77
Station 9	77	77	77
Station 10	77	77	77
Total	768	768	767
OEE	98.23	98.23	98.31

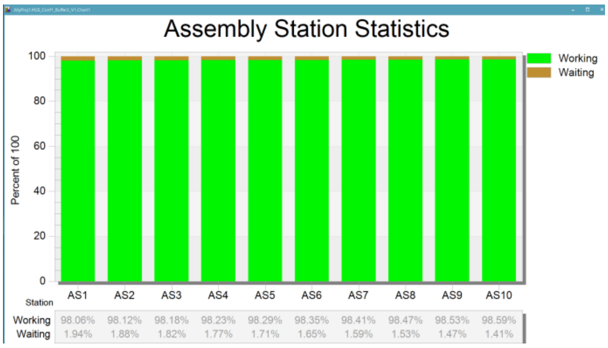

Fig5:OEE distribution over 10 stations of scenario 1

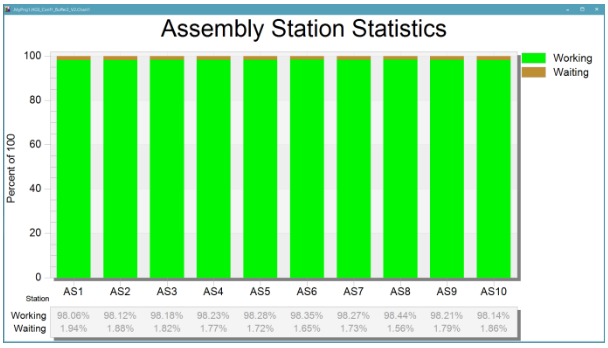

Fig6:OEE distribution over 10 stations of scenario2

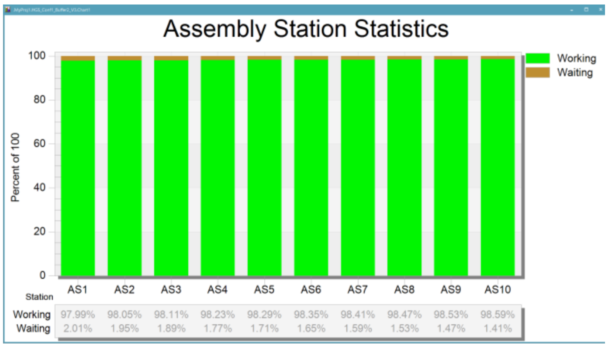

Fig7:OEE distribution over 10 stations of scenario3

4.2.3. Combination 3: produce products with a processing time of around 5 minutes

Select productcode C1 – S with processing time 4'02 distributed to stations 1, 2 and 6, C2 – S with processing time 5'28 distributed to stations 3, 5 and 9, U1 – S with processing time 3'20 distributed to stations 4, 7, 8 and 10.

Number of products produced and OEE of each station are given in Table 5. Distribution of OEE over 10 stations of 3 control solutions is shown in Fig.8, Fig.9 and Fig.10.

Table 5.Number of products and OEE of each station

	Scenario 1	Scenario 2	Scenario 3
Station 1	93	88	93
Station 2	93	88	93
Station 3	72	72	72
Station 4	105	106	106
Station 5	72	72	72
Station 6	93	88	88
Station 7	100	107	107
Station 8	97	108	108
Station 9	73	72	72
Station 10	94	109	109
Total	829	871	920
OEE	94.79	92.58	97.12

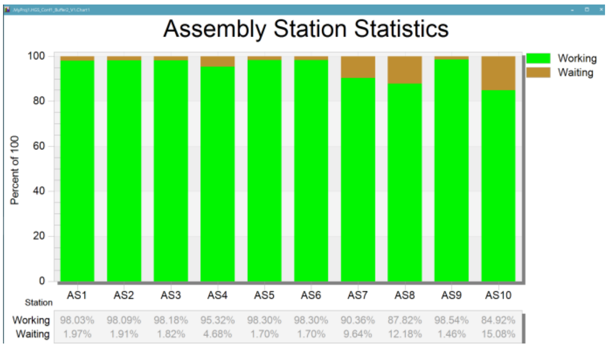

Fig8:OEE distribution over 10 stations of scenario 1

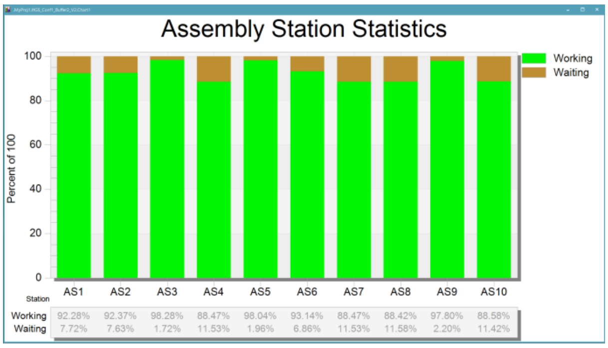

Fig 9:OEE distribution over 10 stations of scenario2

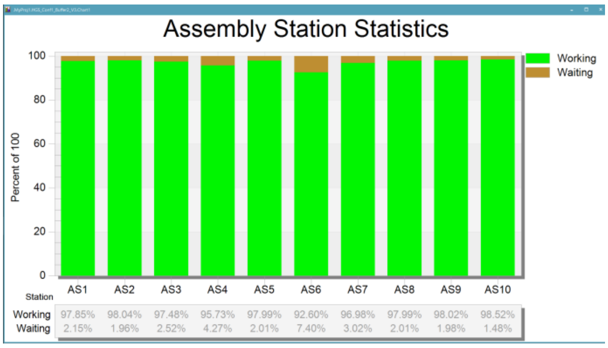

Fig10:OEE distribution over 10 stations of scenario3

Remarks:

- With control solution 1, the first stations have the largest OEE and gradually reduce to the last stations according to the idea of this method that the station that works fast will maximize the OEE.
- With control solution 2, stations 1, 2, 6 or 3, 5, 9 or the rest of the group have the same assembly time, so the OEE distribution is the same, following the idea of the method of evenly distributing the OEE over the processing time.
- With control solution3, stations tend to equal OEE because this method distributes trays to stations so that stations have the least waiting time.

Comments:

- When the assembly time of all stations is less than the assembly time of the designed system (5’), the OEE of some stations did not meet the target because the system did not deliver the trays in time.

Obviously, all three control methods have proved this statement.

- Conversely, when the assembly time of all stations is greater than the assembly time of the design system (5’), the OEE of the stations will be maximized. Clearly, all three control methods have proved this claim.
- In the remaining case, when manufacturing, the combinations have a fast or slow processing time compared to the assembly time of the design system (5’), then control solution 3 gives the best results. The slow production stations, the tray will prioritize over the faster stations, so the fast production stations will have to wait less, thus optimizing OEE.

4.2.4. Sensitivity analysis

This section presents the influence of parameters such as conveyor speed, SKU allocation time, etc. on the overall result (OEE) of the system.

Fig.11 shows the effect of conveyor speed on OEE results for all 3 control solutions.From the figure, OEE does not increase when the transfer speed is larger than the design parameter.This survey shows that it is not possible to improve OEE based on conveyor speed changes.If the conveyor speed is reduced below design parameters, it can lead to a sudden drop in OEE.

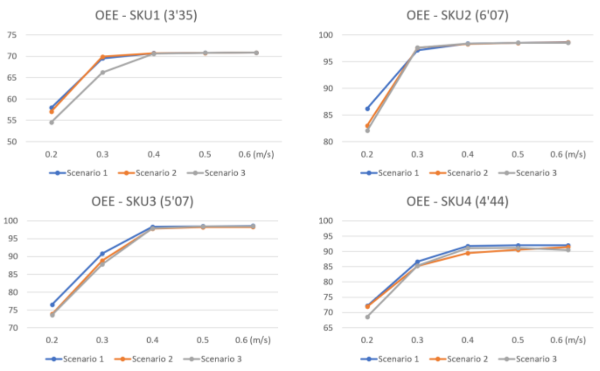

Fig11:OEE distribution according to conveyor speed

Fig. 12 shows the effect of lifter speed on OEE results for all 3 control solutions.From the figure, OEE does not increase with increasing lifter speed above design parameters.This survey shows that it is not possible to improve OEE based on changing lifter speed.Lowering the lifter speed below design parameters can result in a sudden drop in OEE.In addition, it is possible to reduce the lifter speed to 0.2 m/s and still ensure OEE.

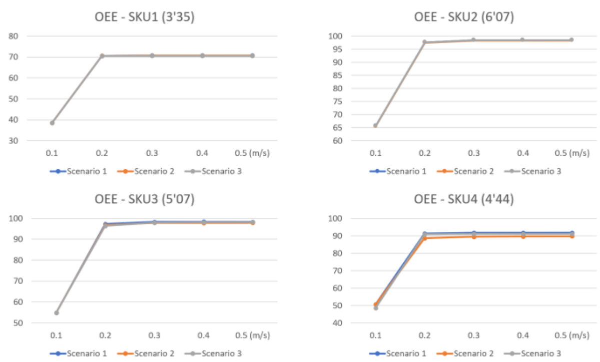

Fig. 12:OEE distribution according to lifter speed

Fig. 13 shows the effect of SKU loading time on OEE results for all 3 control solutions.The results of the previous 2 cases showed that it was not possible to increase OEE based on increasing the velocity parameter.In this case, OEE increases significantly if loading time is reduced.For large OEE values, it is already saturated, so reducing the load time is not significant.In addition, OEE decreases significantly with increasing load time.That is, all system parameters must satisfy a minimum threshold.

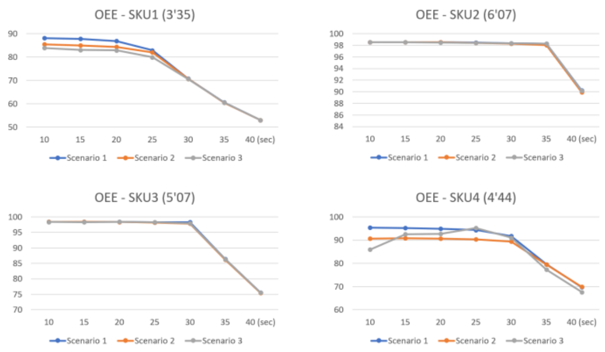

Fig13:OEE distribution according to SKU loading time

5. CONCLUSION

In this paper, the Tecnomatix Plant Simulation softwareis used to evaluate system design parameters as well as control methodsin the mattress factory.Simulation results for each control method show that control option 1 (tray distribution) is the most suitable. The results of the sensitivity analysis also show that the system only achieves the desired results in a certain parameter range.These results help to choose the best parameters to operate the system.

Future work will use optimization tools, such as Genetics Algorithm (GA)for checking all production SKU combinations, from which it is possible to select the best set of parameters for the system when manufacturing mattresses with all combinations to achieve the greatest possible productivity.

6. ACKNOWLEDGMENT

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