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The Implementation of Simulation in Designing Production Expansion

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Abstract: This paper addresses the design of production expansion by using simulation to optimize production and storage capacities. The primary objective is to apply the Siemens Tecnomatix Plant Simulation software version 2404 to analyze the current production process, identify potential bottlenecks, and propose improvements. The methodology involves the use of simulation to create digital models of the production process, allowing for the detection of issues and evaluation of alternative solutions without interfering with ongoing production. The novelty of this approach lies in its ability to test and optimize the production flow digitally, ensuring a smoother transition to expanded capacities. Several alternative scenarios for production expansion were developed using Siemens Tecnomatix Plant Simulation, with a focus on verifying production volumes, identifying bottlenecks, and proposing the necessary machines and technological equipment. The results of the simulations are used to assess the proposed improvements, while the layout of the process is optimized for efficient material flow. The paper also presents 3D models as part of the solution proposal. The findings demonstrate the effectiveness of simulation-based design for expanding production systems, offering a methodology that can be applied to similar manufacturing processes.

Keywords: simulation; production expansion; methodology of planning production; bottleneck; mapping of production processes

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1. Introduction

The presented paper deals with the implementation of the Siemens Tecnomatix Plant Simulation software version 2404 in the design of production process expansion in response to increased market demands.

In today's competitive market, manufacturing companies face considerable price pressure and high demand fluctuations, which challenge them to produce products in a cost-effective manner. Serial and variant manufacturers, in particular, aim for optimal capacity utilization to avoid overcapacity and minimize fixed production costs. By using current strategies, companies can respond to market fluctuations by adjusting their production systems within a predefined flexibility range [1,2].

In the rapidly evolving market environment with increasing unpredictability, a factory must quickly adjust its production capacities with minimal effort. This paper presents an innovative methodology that recommends the most effective approach for capacity planning to modify production volumes, incorporating the implementation of simulation in designing production expansion [2].

Tsai, J.F., Wang, P.C., et al. [3] discuss several models for production planning and optimization in their contribution. The authors base their results on deductive graphs. In our study, however, the results are grounded in simulation models. In today's era, where the digitalization of processes is heavily addressed, this method of evaluation is considered more suitable for future potential use of these models.

Holtewert, P. and Bauernhansl, T. [4] examine the capacity utilization of manufacturing processes and their associated costs. They also focus on eliminating bottlenecks in such serial and large-capacity processes. In the case study, the increase in manufacturing capacity is similarly addressed, as the product diversity is also taken into account in relation to the varying volumes of production across different lines, considering the assortment of products.

It is also necessary to focus on minimizing bottlenecks as much as possible. Sarjono, H., Kusuma, V., et al. [5], as in our case, deal with the increase in manufacturing capacity when demand for the company's products exceeds supply. This situation is also present in our case study, where the company plans to increase production capacity by more than 120% based on future customer demand estimates. Such an intervention in the production process, however, requires eliminating potential future bottlenecks that could arise from this capacity expansion.

Similarly, Huang, D., et al. [6] address production capacity in their contribution but focus more on batch sizes and the associated reservation costs. In our case, production batch sizes on different lines vary depending on the product range and customer orders, requiring adjustment of production lines accordingly.

Schwarz, J.A. and Tan, B. [7] analyze the production capacity of manufacturing processes during product transitions. They examine how to determine production levels for old products when switching to new ones. In our case study, however, the issue is not just about increasing production capacity in terms of quantity but also determining the necessary equipment for current and future lines. In the packaging process, certain constraints were faced in terms of warehouse space and the number of finished product pallets. Even from this perspective, it became clear that not every positive outcome in terms of simulation results could be considered acceptable, given the pallet dimensions and the available space in the intermediate warehouse where the packaging occurs.

Creutznacher, T, et al. [8] discuss the production capacity per shift in the automotive industry. While our case study is not related to the automotive industry, similarities can be found in the algorithms used to solve the required production volume in both cases and the simulation verification of the examined and analyzed proposals.

Building on the theoretical insights obtained from the presented literature review, a methodology for applying Siemens Tecnomatix Plant Simulation software in production expansion was formulated.

The aim of this paper is to implement the proposed methodology in the design of production expansion. The proposed methodology was validated in a manufacturing company that has reached a certain level of development and is approaching the limits of its current production and warehouse capacity (approximately 1.2 billion units per year). The solution to this design also includes the analysis of material flows in the production process (material inputs and finished products). The outcome was the identification of bottlenecks in the production process and the evaluation of process performance in relation to the planned automation. For the purposes of our analysis, simulations of several alternative scenarios were conducted, which will be discussed in the following chapters [9,10].

2. Materials and Methods

This section provides a concise and precise overview of the experimental results, their interpretation, and the conclusions that can be drawn from the analysis [10], while the following section introduces methodologies for analyzing the manufacturing process, material, and logistical flow using the software tool Plant Simulation version 2404 [11–13].

Figure 1 illustrates the methodology for analyzing manufacturing processes using the Plant Simulation module and the steps involved in executing it through the algorithm. It highlights the parameters required for this analysis using the software. The final result of the analysis is the simulation of the manufacturing process [13,14].

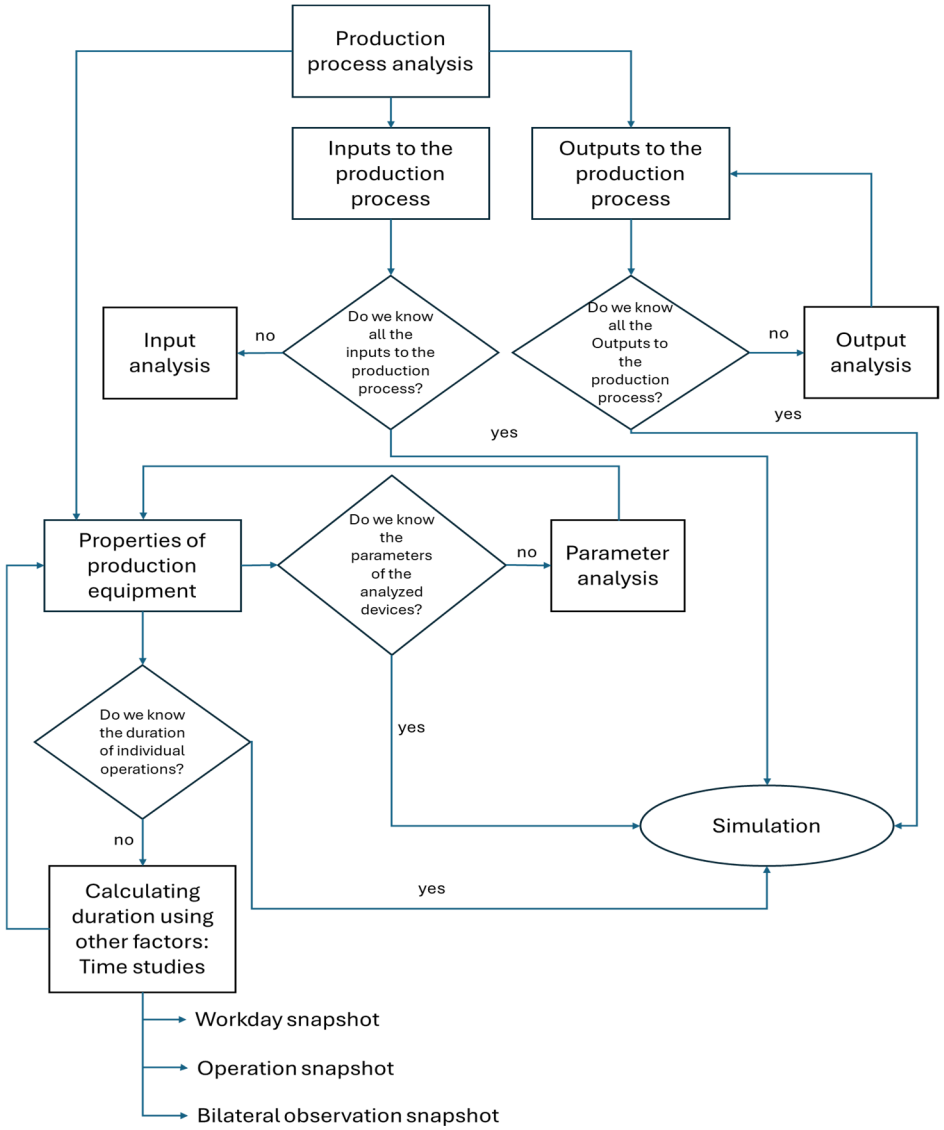


Figure 1. The algorithm for analysis of the production process using Siemens Tecnomatix Plant Simulation.

Another algorithm outlines the methodology for analyzing and optimizing material and logistical flows in the Plant Simulation software version 2404 [15]. This algorithm shows its connection to the algorithm in Figure 2 and highlights the need to incorporate its application into this issue. Its outputs can either be a simulation of the manufacturing process, taking into account material and logistical flows, or the process may be concluded without it, if the possibilities for improvement in inventory management are unknown [16,17].

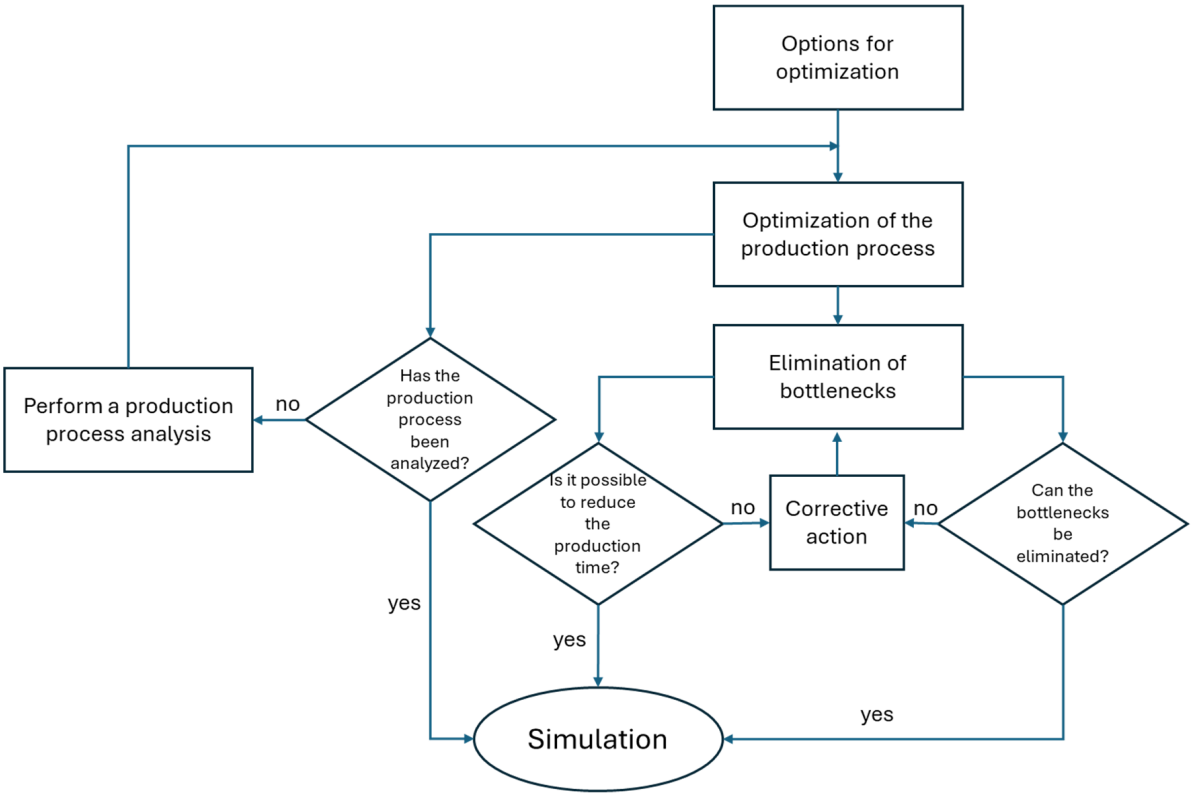


Figure 2. Algorithm for analyzing material and logistical flows using Siemens Tecnomatix Plant Simulation.

The manufacturing company addressed in this study of production capacity expansion is engaged in the production of eco-friendly food packaging. Specifically, it produces paper bags for various types of bakery products, which are commonly encountered in daily life when shopping at retail stores. The bags are made in different sizes and designs, either fully paper or a combination of paper and transparent film. These bags are often used as packaging for baguettes, rolls, and similar products. The product range of these packaging items is quite broad, and as a result, the production parameters on individual lines are set in various ways depending on the type of product currently being manufactured. Very often, each line produces a different type of product, which leads to differences in production parameters and production time based on orders and customer requirements. Customers include various retail chains both domestically and internationally, as well as companies producing bakery products and similar items. For example, manufacturers of filled baguettes, sandwiches, rolls, and the like. These customers package their finished products in the packaging produced on the company's manufacturing lines. The company itself does not wish to be named or specifically identified in the publication, so its name and location are not disclosed.

The production line itself consists of several parts, such as unwinding recycled paper from a large roll, followed by cutting the paper to the required sizes based on the type of product being produced. For some products, the paper is layered and then folded into the desired shapes. The bags are then glued, stacked in the required number of pieces for each package, and subsequently packed according to the specified volume onto pallets. As mentioned in later sections of the paper, some products are packed into boxes and then onto pallets, while others are packed directly onto pallets. The packing process depends on customer requirements and adherence to production standards. For the production of bags with a transparent window, perforated transparent film is also used, which is adhered to the respective bags during the production process.

The lines currently used by the company, and which they plan to purchase in the future, are primarily single-track lines that produce one type of product on each machine track, with products being removed for stacking and further packing based on other rules and requirements. However, the company plans to acquire dual-track lines, which will allow for the production of a significantly higher volume of products in comparable timeframes. These machines will also utilize a more efficient packing method known as palletizing. The focus of the study is on the applicability of these additions to the production lines, determining the required number of these machines for effective use in the planned production expansion.

All pallets with products undergo stretch wrapping, which involves packaging the pallets in stretch film to ensure greater stability during transportation, either from the production area to storage or to the customer. With the increase in production capacity, it was essential to address the operation and number of these machines. Furthermore, the available space used for these activities, once production on the lines is completed, limited both the number of these machines and the number of pallets that could wait for processing. For this reason, some variants that could meet capacity requirements for successful use had to be re-evaluated, as the space in the main production hall, where the production expansion is planned, is also being expanded. However, the space for stretch wrapping and packing machines does not have such expansion potential, and they will need to fit within the existing area, albeit with the difference that these machines will operate continuously, rather than on a single shift. Under single-shift operation, finished products were stored in this space and acted as intermediate storage before being completed and transferred to the warehouse. In the proposed model, pallets waiting to be completed will no longer be stored in these areas but will be processed continuously and moved directly to storage.

3. Results

The proposed methodology was thoroughly validated in the production environment of a selected company, and the results of this validation are discussed in detail in the following chapter.

3.1. Projection of the Production Process After the Implementation of the Production Expansion Project

Methodologies for analyzing the manufacturing process, material, and logistical flow were applied to the manufacturing process, which is schematically represented in a simplified form in Figure 3 [18].

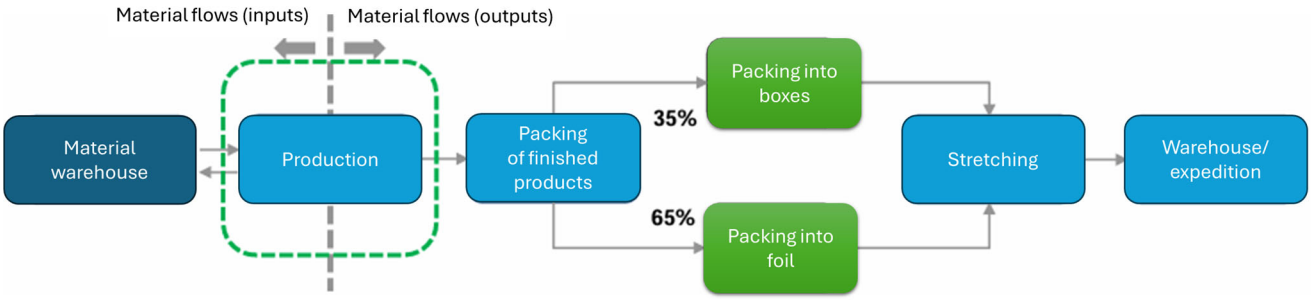


Figure 3. Production process flowchart.

The project aims to verify the properties of the production process, which, in its final form, will consist of 16 production lines. Currently, production is equipped with eight lines, capable of producing an average output of 4,595,000 units/24 h. After the production expansion, the estimated output of a line, with a total of 16 machines, is expected to reach 10,925,000 units/24 h. The design includes four machines from the original

eight lines, along with four new machines that can produce 75% more units than the others; these are dual-track machines. The anticipated increase in production is estimated at 6,330,000 units/24 h. The current average distribution of production across different product types is provided in Table 1.

Table 1. Setting of individual machines before production expansion.

Setting of Individual Machines					
Machines	**Pallets/24 h**	**Boxes**	**Pieces Per Box**	**Disc Cutting Rate in pcs/h**	**Total Number of Pieces**
1.	10	100	1000	45,000	1,000,000
2.	9	100	1000	40,000	900,000
3.	15	60	500	20,000	450,000
4.	13	70	500	20,000	455,000
5.	11	80	500	20,000	440,000
6.	10	90	500	20,000	450,000
7.	9	100	500	20,000	450,000
8.	9	100	500	20,000	450,000
Sum	86	700	5000	205,000	4,595,000

The expansion of production is expected to result in an increase in output, as shown in Table 2.

Table 2. Setting of individual machines after production expansion.

Setting of Individual Machines					
Machines	**Pallets/24 h**	**Boxes**	**Pieces Per Box**	**Disc Cutting Rate in pcs/h**	**Total Number of Pieces**
9.	10	100	1000	45,000	1,000,000
10.	15	60	500	20,000	450,000
11.	11	80	500	20,000	440,000
12.	18	50	500	20,000	450,000
13.d	31	50	500	35,000	775,000
14.d	18	90	500	35,000	810,000
15.d	23	70	500	35,000	805,000
16.d	16	100	1000	70,000	1,600,000
Sum	142	600	5000	280,000	6,330,000

The company manufactures various product variants, which makes it necessary to adjust the machine distribution according to the average values of the current production output. Therefore, the values differ across individual production lines. Currently, with eight machines in operation, the production is carried out with the following packaging method.

Product packaging process:

- A total of 65% of pallets from the machines proceed to the packaging machine.
- The time to package one pallet on the packaging machine is 36 min.

- A total of 35% of pallets go directly from the production machines to the intermediate warehouse for pallet stretch wrapping.
- The average stretch wrapping time for one pallet is 6 min per pallet.
- A total of 100% of the produced pallets are stretch-wrapped. A total of 65% of the pallets wrapped on the packaging machine are moved to the intermediate warehouse for stretch wrapping.
- Stretch wrapping currently takes place during 8 h per day.

These operations occur behind the production lines, and it is essential to determine the necessary number of these operations and machines when expanding production in order to ensure the packaging and transport of the entire volume of both current and new production to the output warehouse. The 65:35 packaging ratio should be maintained in the future as well. It is necessary to verify the justification for implementing a palletizer in the packaging process. The palletizer can be used for packaging with dual-track machines and can package five times more products than these machines can produce. By using the palletizer, the packaging machines can be eliminated for these machines, and all products from these four machines can proceed directly to the stretch wrapping process and then to the output warehouse.

Based on the mentioned methodologies, the necessary analyses were performed in the manufacturing process, and several simulation models were created to verify different variants of fulfilling the conditions for expanding production capacity and packaging in the required scope. A total of eight simulation models were created, one of which simulated the original state of production with eight production lines, while the other seven variants worked with the distribution of production in the expanded version, addressing not only the production volume but also the method of packaging finished products.

3.2. Simulation of Alternative Scenarios

The current state of production is considered to be the manufacturing operation where there are currently seven machines, but according to the task, an additional machine needs to be taken into account, which should be implemented into production during this period. Therefore, for the simulation of the current state, the given data were transferred to eight production machines operating continuously for 24 h. The production parameters for the individual machines are shown in Table 1 for the eight machines in the current operation. The simulation results indicate that the production machines produced 86 pallets, but only 69 pallets reached the finished goods warehouse. This is because 65% of the total amount passes through the packaging machine, which has an operational time of 36 min per pallet. During 24 h of operation, this packaging machine was able to pack 39 pallets, and there were still 16 unwrapped pallets waiting in the intermediate warehouse before this machine. At the end of the simulation, one pallet was in the packaging machine, and packaging was in progress, with the packaging machine utilization at 90.81%. All 69 completed pallets went through stretch wrapping, which is the final step in production before the finished pallet is sent to the finished goods warehouse.

In the current production operation, stretch wrapping takes place over an 8 h interval during the total workday. The simulation results show that the stretch wrapping machine's activity is sufficient to handle its tasks with the current production volume during the 8 h operation. The utilization of the stretch wrapping machine, based on the simulation results, is 26.54%, indicating a significant reserve capacity in this process.

The number of pallets in the finished goods warehouse + pallets waiting for packaging + pallets in the packaging machine = total number of pieces produced by the machines.

$$69 + 16 + 1 = 86 \text{ pallets}/24 \text{ h}/8 \text{ machines}.$$

One of the main tasks of processing this project is to verify the suitable method of packaging products at the output of production. In the current state, packaging is carried out in the manner described above, where 35% of the products are packaged directly on the machines into boxes in designated production batches, and these boxes are placed in a specific number on a pallet, which then moves directly from the production machine to the intermediate warehouse, where it waits for the final step in production, which is the stretch wrapping of the pallet.

The remaining 65% of the production output from the machines passes through the packaging machine, which has an operational time of 36 min per pallet. As seen from the simulation of the current state, even now, the packaging machine is not capable of packaging the amount produced by the current machines. Packaging on the packaging machine can be considered the largest bottleneck in the entire production process. The task of verification through simulation is to determine the required number of packaging machines for the planned production expansion so that the 65:35 packaging ratio remains the same as in the current form. At the same time, it is necessary to account for the increase in production, the number of packaging machines, and also the increase in the number of stretch wrapping machines and their operational mode.

Currently, there is one stretch wrapping machine in operation, which is able to wrap the entire 24 h production volume in 8 h of operation. In the future state, it is necessary to verify how many such machines, and with what operating time, will be needed to handle the increased production volume.

In the simulation models, several variants were verified both at the material input to the production process and at its output. After consultations with the company management, a conveyor was added for each machine compared to the current state. This conveyor automatically transports the finished pallets with products from the production machines to the area next to the main production hall, where the packaging and stretch wrapping machines are located. For simplicity in the simulation, buffers were created at both the input to the production devices and the output from them, similar to the ones at the input. Thus, for every two machines, one buffer was created at the output from the production. In total, eight buffers were created at the output from 16 production devices in the main production hall. From each output buffer, part of the conveyor belt leads to one main conveyor, which transports the pallets to the area where the packaging and stretch wrapping machines are located. The packaging machines are connected to both intermediate warehouses so that each packaging machine is linked to each intermediate warehouse, and thus, the available packaging machine always packages the pallet.

Of the variants examined and verified by the simulation models, only those that, under certain circumstances, would be acceptable and feasible to implement in the company's conditions will be mentioned below.

3.2.1. Verification of Production with the Implementation of Four Packaging Machines and Two Stretch Wrapping Machines Operating 24 h a Day

One of the variants implemented was the one in which four packaging machines and two stretch wrapping machines would be used for packaging the produced products during 24 h of operation. The results of this proposal were as follows:

- The finished goods warehouse contains 224 fully completed pallets after 24 h of production.
- In the first intermediate warehouse before the packaging machines, there are no unwrapped pallets.
- In the second intermediate warehouse before the packaging machines, there are no unwrapped pallets.

- The packaging machines are connected to both intermediate warehouses, so each packaging machine is linked to each warehouse, ensuring that the available packaging machine always packages a pallet.
- Packaging machine No. 1 wraps 36 pallets.
- Its utilization is 80.21%.
- Packaging machine No. 2 wraps 36 pallets.
- Its utilization is 80.08%.
- Packaging machine No. 3 wraps 37 pallets.
- Its utilization is 82.37%.
- Packaging machine No. 4 wraps 36 pallets.
- Its utilization is 80.43%.
- At the end of the simulation, each packaging machine has one pallet still being processed.
- Stretch wrapping machine No. 1 wrapped 115 pallets with a utilization of 42.64%.
- Stretch wrapping machine No. 2 wrapped 109 pallets with a utilization of 40.37%.

The number of pallets in the finished goods warehouse + pallets waiting for packaging + pallets in the packaging machines = total number of pieces produced by the machines = 224 + 0 + 4 = 228.

From the simulation perspective, this variant was suitable for implementation, but after calculating the area of the intermediate warehouse, it became clear that after 12 h, the space required for storing the pallets would significantly exceed the available area in this facility. From this standpoint, the proposal was evaluated as unacceptable after consultation with the company management. Schema and simulation of production with the implementation of four packaging machines and two stretch wrapping machines are shown in Figures 4 and 5.

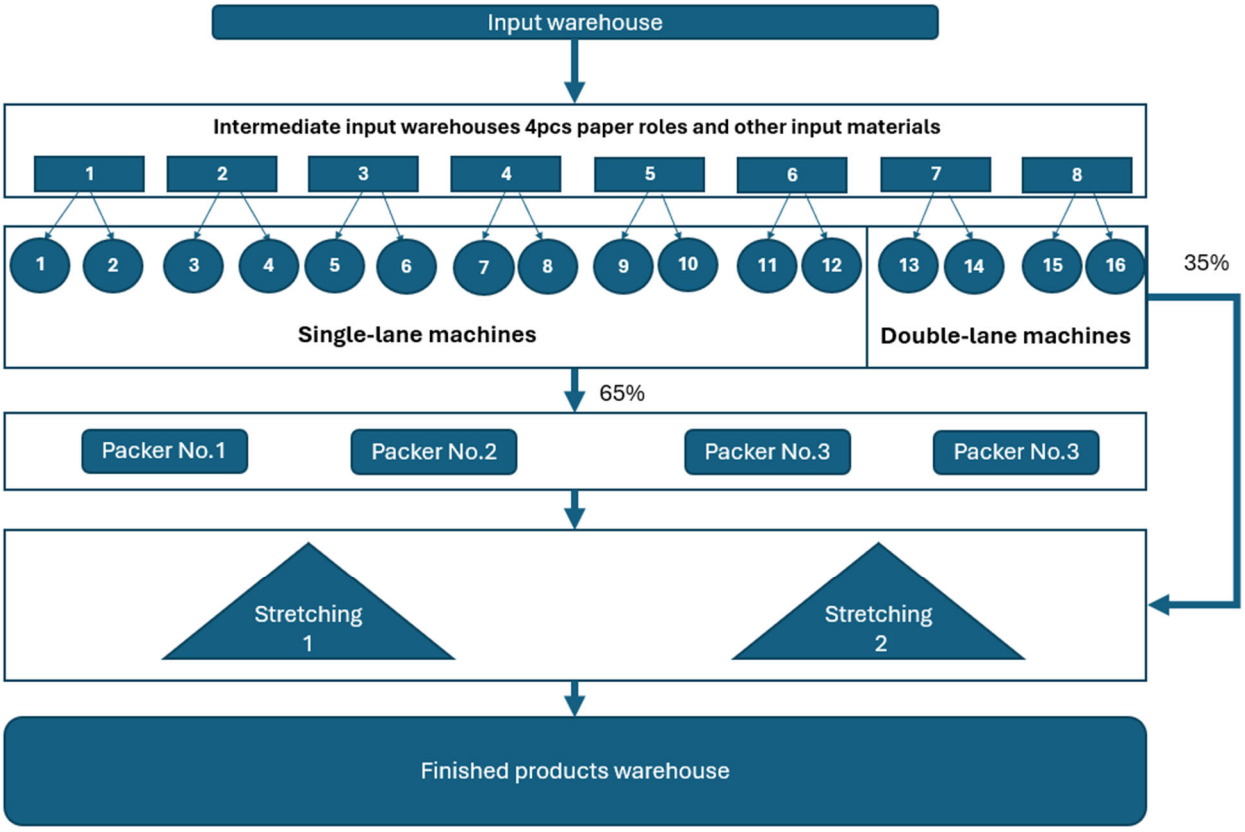


Figure 4. Schema of production with the implementation of four packaging machines and two stretch wrapping machines.

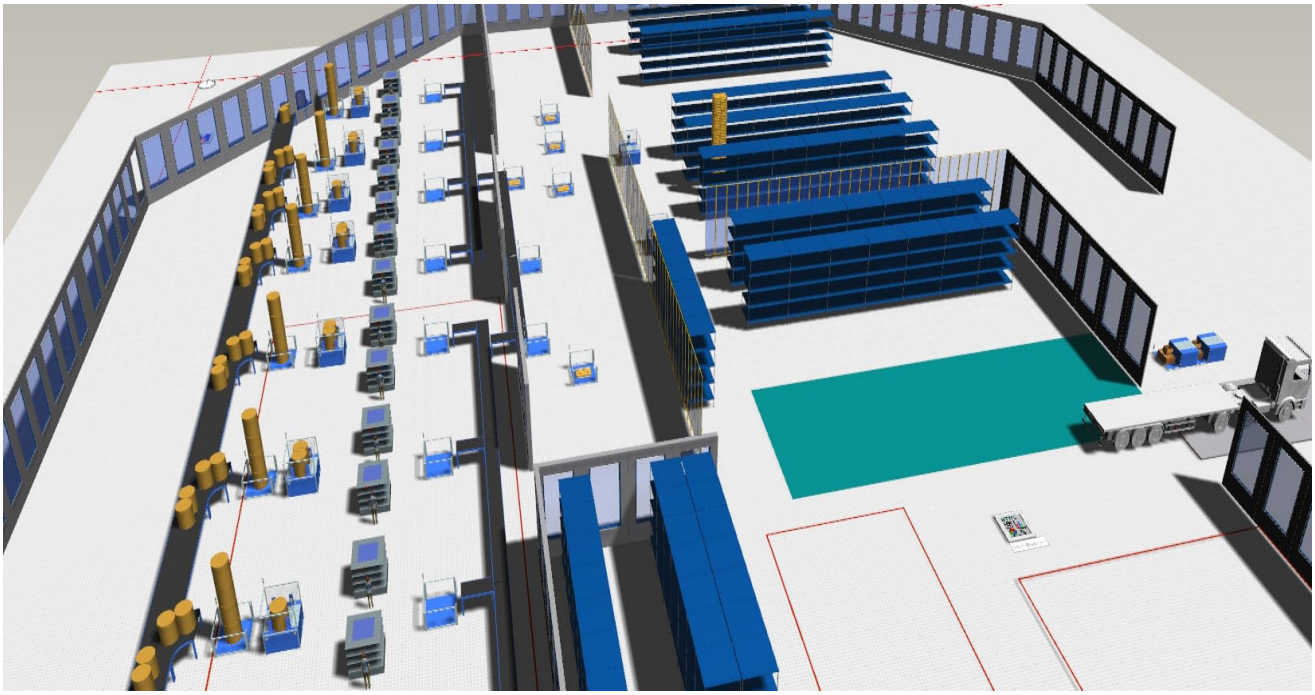


Figure 5. Simulation of production with the implementation of four packaging machines and two stretch wrapping machines.

3.2.2. Verification of Production with the Implementation of a Palletizer, Two Packaging Machines, and Two Stretch Wrapping Machines Operating for 24 h of Production

A variant was also verified where only two stretch wrapping machines would be used in the production process, operating continuously throughout the entire working day and wrapping pallets smoothly for the full 24 h.

The results of the simulation show the following:

- The finished goods warehouse will contain 212 fully completed pallets.
- A total of three pallets will be waiting for stretch wrapping.
- A total of 11 pallets will be waiting before the packaging machines.
- Packaging machine No. 1 will wrap 40 pallets with a utilization of 91.21%.
- Packaging machine No. 2 will wrap 40 pallets with a utilization of 91.47%.
- At the end of the simulation, there is still one pallet in each packaging machine, totaling two pallets in the packaging machines.
- Stretch wrapping machine No. 1 wraps 107 pallets with a utilization of 40.36%.
- Stretch wrapping machine No. 2 wraps 105 pallets with a utilization of 39.29%.

The number of pallets in the finished goods warehouse + pallets waiting for packaging + pallets in the packaging machines + number of pallets waiting for stretch wrapping = total number of pieces produced by the machines = 212 + 11 + 2 + 3 = 228.

Schema and simulation of production with the implementation of a palletizer, two packaging machines, and two stretch wrapping machines are shown in Figures 6 and 7.

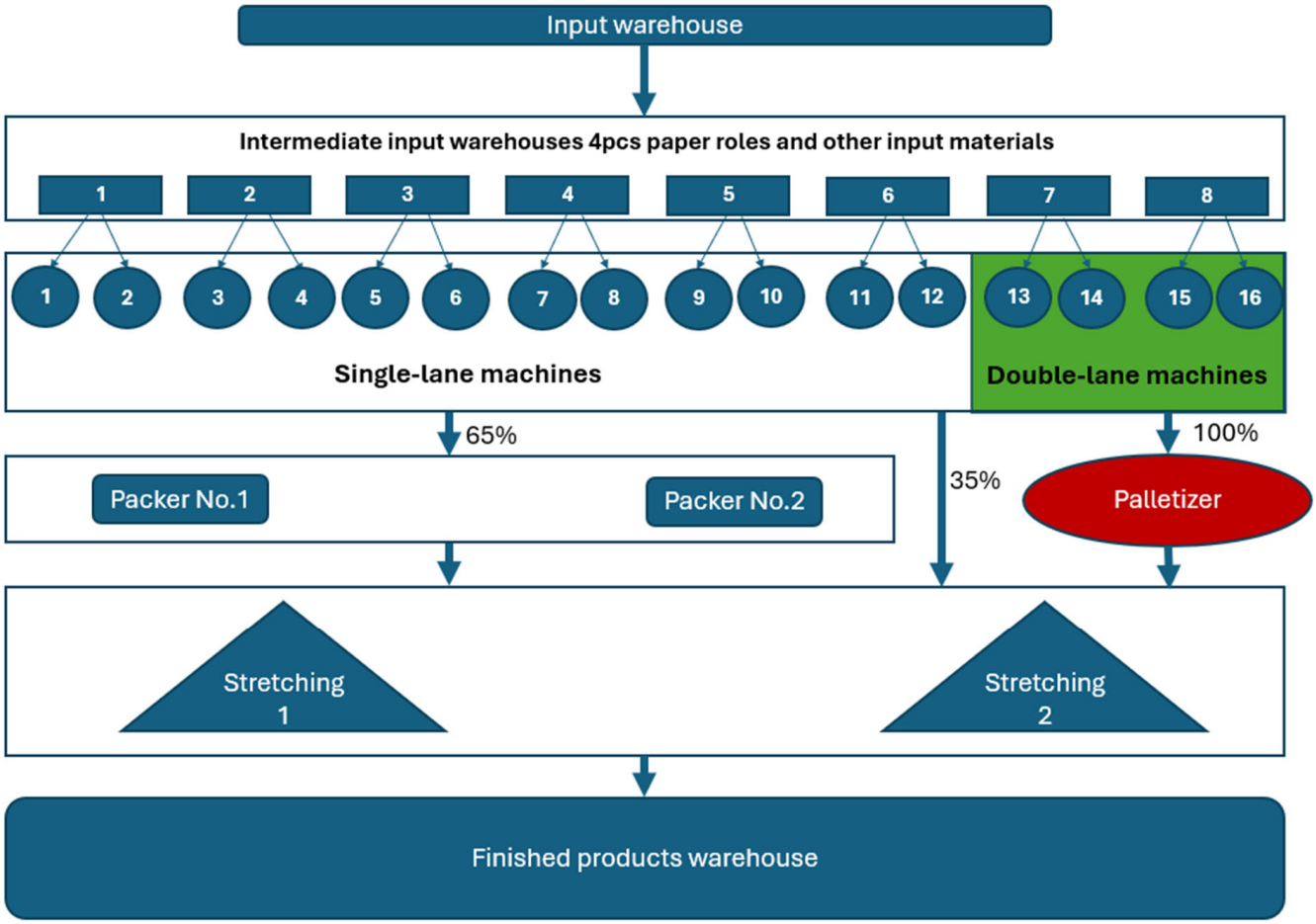


Figure 6. Schema of production with the implementation of a palletizer, two packaging machines, and two stretch wrapping machines.

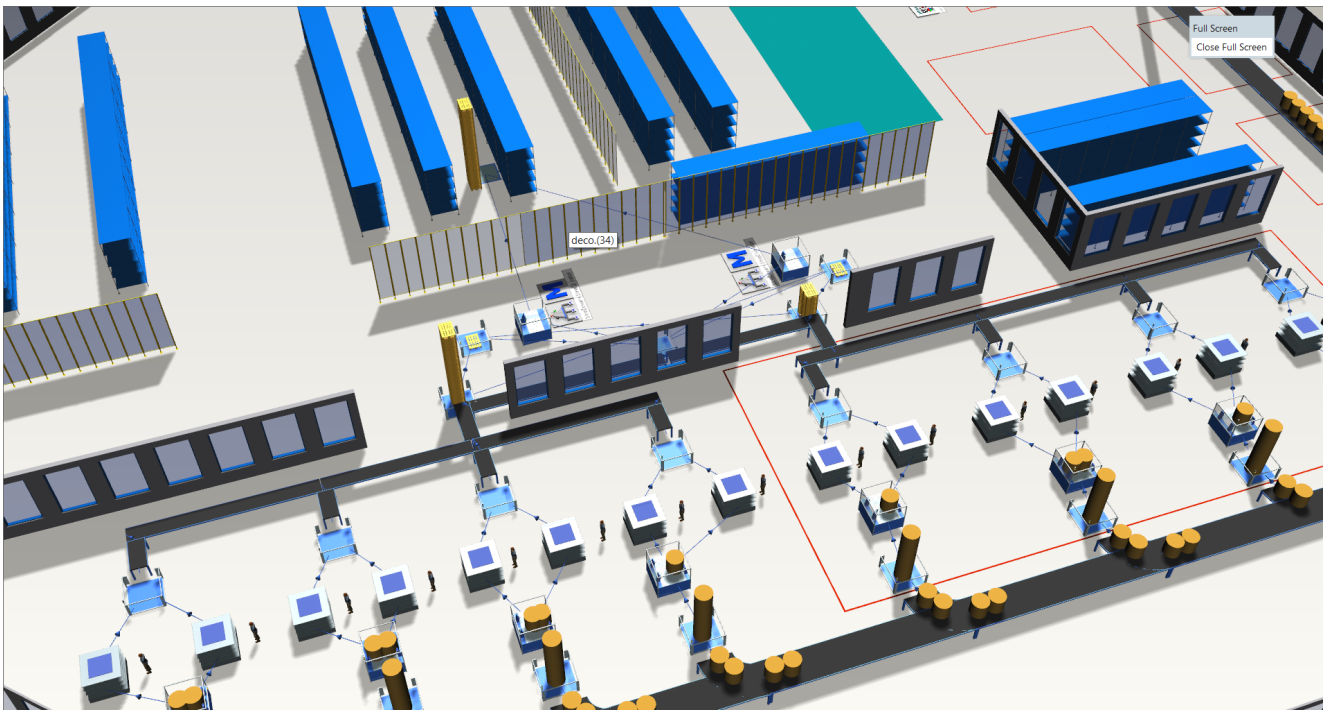


Figure 7. Simulation of production with the implementation of a palletizer, two packaging machines, and two stretch wrapping machines.

3.2.3. Verification of Production with the Implementation of a Palletizer, Three Packaging Machines, and Two Stretch Wrapping Machines Operating for 24 h of Production

The most suitable variant in terms of completed and packaged pallets turned out to be the one where three packaging machines, a palletizer, and two stretch wrapping machines are implemented, with a continuous 24 h operation. This simulation produced the following results:

- The finished goods warehouse will contain 225 fully completed pallets.
- There will be 0 pallets waiting before the packaging machines.
- Packaging machine No. 1 will wrap 32 pallets with a utilization of 71.25%.
- Packaging machine No. 2 will wrap 32 pallets with a utilization of 71.53%.
- Packaging machine No. 3 will wrap 26 pallets with a utilization of 57.98%.
- At the end of the simulation, there will still be three pallets waiting for stretch wrapping.
- Stretch wrapping machine No. 1 will wrap 114 pallets with a utilization of 42.25%.
- Stretch wrapping machine No. 2 will wrap 111 pallets with a utilization of 40.78%.

The number of pallets in the finished goods warehouse + pallets waiting for stretch wrapping = total number of pieces produced by the machines = 225 + 3 = 228.

Schema and simulation of production with the implementation of a palletizer, three packaging machines, and two stretch wrapping machines are shown in Figures 8 and 9.

The production capacity on all lines was set in all the examined variants according to the tables provided above, meaning that in each variant, the diversity of the company's production range was taken into account.

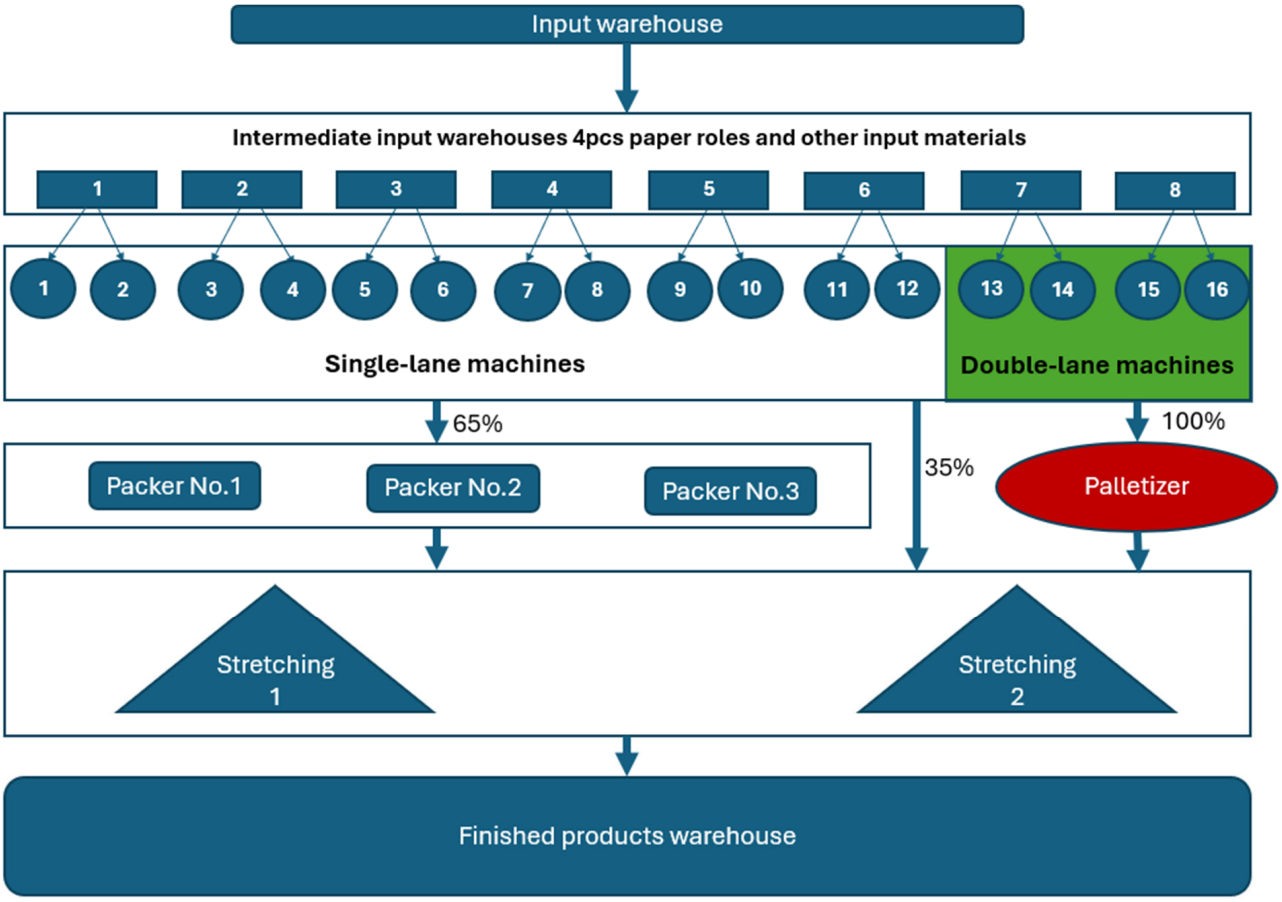


Figure 8. Schema of production with the implementation of a palletizer, three packaging machines, and two stretch wrapping machines.

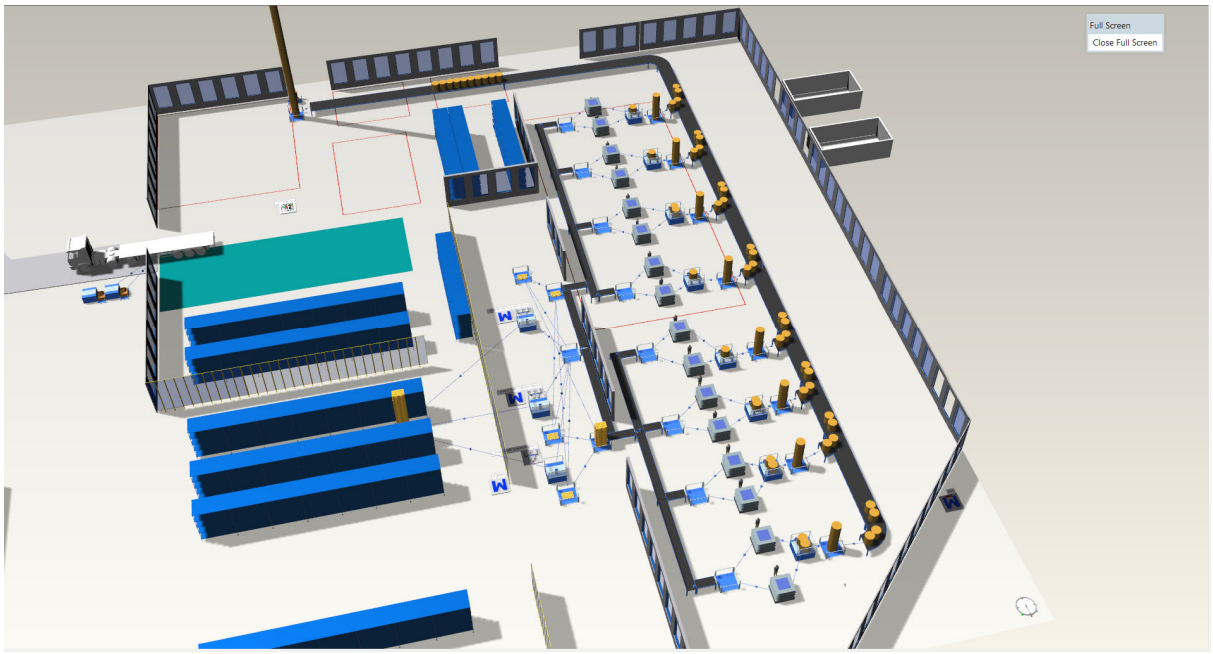


Figure 9. Simulation of production with the implementation of a palletizer, three packaging machines, and two stretch wrapping machines.

4. Discussion

Based on the simulation, it is clear that even without further expansion of production, the bottleneck in handling the finished production is the packaging machine. The insufficient capacity of the packaging machine creates the need for additional packaging during peak production periods (requiring at least one more packaging machine over the weekends). The planned expansion of production by eight new production machines (including four double-lane machines) will lead to a 165% increase in production under a 24/7 operation. Given the spatial limitations of the company, after the expansion, it will be necessary to combine the existing solution with an automated system (palletizer)—i.e., the existing production: manually operated packaging machine (1 + 1) and the new production: palletizer in combination with the packaging machine. Taking into account the gradual ramp-up of production, it is proposed that the implementation be divided as follows: Scenario 2 (medium-term horizon) and then Scenario 3 (long-term horizon).

The submitted contribution and case study, conducted in a real company and production process, base their analyses, evaluations, and proposals on the outlined methodologies for analyzing the production process and subsequently optimizing it using the simulation software Siemens Tecnomatix Plant Simulation version 2024 [19,20]. The results presented can be incorporated into the planning of the company's future development, both in the mid-term and long-term, and on this basis, the suitability of the various acceptable scenarios from the simulation models is also evaluated [21–23].

The equipment utilization in our case study ranges from 83% to 86% for the production lines, while the utilization of the packaging machines is at 91.5%, which leaves little room for production reserves and further increases, especially in the scenario that was partially deemed acceptable in the short-term horizon. The situation is better in the case of packaging machines under the fully acceptable scenario, with three packaging machines, where the utilization ranges from 58% to 71.5%, providing ample room for future growth. In all cases, the utilization of the stretching machines is 45%, which also provides considerable capacity for future expansion in case of increased demand. Further details of the results from the three simulated process scenarios are provided in Table 3.

Table 3. Results of simulated scenarios.

	Current Process Model	Scenario 1	Scenario 2	Scenario 3
Operational Assumptions				
Number of machines	8 = 7 + 1	16 = 7 + 1 + 4 + 4	16 = 7 + 1 + 4 + 4	
Theoretical maximum production volume	4.6 mil.pcs/24 h	10.9 mil.pcs/24 h	10.9 mil.pcs/24 h	10.9 mil.pcs/24 h
Number of pallets	86 pallets/24 h	228 pallets/24 h	228 pallets/24 h	228 pallets/24 h
Annual production volume	1.6 mil.pcs p.a.	3.8 mil.pcs p.a.	3.8 mil.pcs p.a.	3.8 mil.pcs p.a.
Technological Equipment				
Number of packaging machines	1×	4×	2×	3×
Number of stretch wrapping machines	1×	2×	2×	2×
Palletizer	no	no	yes	Yes
Simulation Results				
Output of production	86 = (56 + 30)	228 (149 + 79)	228 (149 + 79)	228 (149 + 79)
Output structure:	69	224	212	225
Packaging machine	39	145	80	90
Stretch wrapping machine	n/a	n/a	53	56
Boxes	30	79	79	79
Intermediate warehouse	17	4	16	3
Capacity utilization (%)	90.8%	80.8%	91.3%	66.9%
Stretch-wrapped pallets	69 (26.5%)	224 (41.5%)	212 (39.3%)	225 (41.5%)

The results of this paper were derived from the outcomes of simulations conducted at several levels of the production process. Not only the results from increasing the number of production units were considered, but this would lead to production blockages downstream, particularly in the areas of packaging and stacking of finished products. To prevent such bottlenecks, the solution addressed not only the expansion of production, which was a priority, but also the downstream processes of the main production, which also significantly influence the overall production output. The paper by Chu, J.F. et al. [24] addresses production expansion and its verification based on multi-stage validation of the proposed production expansion.

The topic of production capacity expansion is also addressed in the paper by Lin, M.H. et al., (2019) [25]. The authors focused on reformulating a model that determines the optimal levels of production, transportation, and inventory, as well as the optimal operations for batch production and capacity expansion strategies. Several experiments were conducted to demonstrate the effectiveness of the proposed method and the impact of production capacity expansion. In our paper, we examine several alternatives validated through simulation, from which we evaluate the proposed solutions based on the results and the constraints imposed by the given situation.

In the paper by Min, Z; Nie, GH, and colleagues [26], they analyze production bottlenecks and the subsequent increase in production by accelerating the speed of certain devices. In our case study, it was also essential to eliminate the bottleneck, which in our case was the packaging machine, and based on the analysis of the product range as well as the production capacities of the production lines, a strategy for expanding production was planned not only by adding devices that reliably work in the current setup but also by introducing devices capable of increasing production by 75% compared to the existing ones. This included implementing a palletizer, which would efficiently prepare the products from these new and faster machines for the final packaging stage and subsequent export from production.

Another paper addressing production capacity expansion is by Radatz, H. et al. [27]. These authors focus not only on the design of production capacity expansion but also on the assessment of investment risk. This work presents an approach for determining the

best expansion strategies for modular capacity expansion of equipment and compares the results with line-based capacity expansion strategies and conventionally designed plants for a given market demand development using detailed process simulation, similar to our case.

Each of the contributions reaches its results based on its own methodologies and algorithms.

In the field of improving efficiency in manufacturing processes, further research is essential. The algorithms in question should be applied in additional studies of similar nature in practice, which would confirm their universality, regardless of the industry in which they are implemented. Another factor that can significantly contribute to the efficient solution of production efficiency issues is the mapping of the production process itself. In today's era of digitalization and sensor implementation across various areas, companies should consider the most efficient data collection methods when innovating, expanding, or evaluating their production systems. These data can subsequently be analyzed and used for further processing. Within the production and value chain, localization systems such as RTLS (real-time location systems) or others can be integrated into such manufacturing operations. These systems can collect and record data on movements within the production process and be used directly in the creation of simulation models, significantly reducing their development time and increasing the accuracy of their processing. The authors' workplace has access to such technologies in laboratory conditions, as well as a mobile version of this localization technology. In future research activities, the authors plan to implement the collected data and utilize them to improve the efficiency of manufacturing systems.

5. Conclusions

Based on both theoretical sources and practical experience drawn from the analysis presented in this paper, methodologies for evaluating the applicability of Siemens Tecnomatix Plant Simulation software version 2024 have been developed. These methodologies illustrate the interconnectedness and synergies that the PLM software 4.0 module offers in the context of business processes, particularly in manufacturing. The proposed methodologies can be utilized to assess the suitability of this software in enhancing operational efficiency within various types of manufacturing enterprises. The practical relevance of these methodologies has been validated through a real-world case study, where the simulation results are presented and analyzed.

The application of Siemens Tecnomatix Plant Simulation in this study demonstrated its effectiveness in identifying production bottlenecks and improving material flow, both of which are crucial in optimizing production expansion projects. By leveraging simulation, potential errors were detected early, allowing for adjustments in the planning phase without disrupting the existing production process. The simulation tool also facilitated the development of several alternative production expansion scenarios, which were assessed based on performance criteria such as production volume, process layout, and required technological equipment. These findings contribute to the broader understanding of how digital simulation tools can support strategic decision-making and process optimization in manufacturing.

In conclusion, the methodologies outlined in this paper provide a valuable framework for integrating simulation-based approaches into the design and optimization of manufacturing systems. These methodologies not only support the planning of production expansion but also serve as a reference for similar applications across different industrial sectors. By incorporating simulation into the production planning process, businesses can enhance their operational capacity, reduce risks, and make more informed decisions in the pursuit of continuous improvement.

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