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Simulation in the digital factory: A case study

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ABSTRACT

The paper deals with computer simulation to achieve system optimisation for warehouse management on a digital factory model. The Tecnomatix Plant Simulation program is used as a tool for a modern simulation environment. The case study realised two simulation experiments focusing on storage and optimising storage warehouse processes. The study's experiments analysed and solved mutual blockages of forklift trucks in shelf aisles and determined the optimal number of forklift trucks in the logistics system involved in loading and unloading trucks. Collisions between service and handling equipment in the aisles can restrict or block material flow from the warehouse to production. Therefore, it is necessary to change the arrangement of individual materials in the warehouse and determine the optimal number of service and handling equipment.

Keywords: simulation, logistics, digital factory, warehouse.

INTRODUCTION

Warehouse management is a significant part of logistics and affects its operation and overall success. The warehouse management system and its design help improve every aspect of enterprises and production companies' operations and implement an organised approach to management. Also, effective warehouse management is a significant competitive factor in any supply chain.

Therefore, modern, effective, innovative ways are suitable for achieving the optimal warehouse management system. One possible tool is applying a digital factory's simulation approach and philosophy.

Several authors and research studies deal with the issue of warehouse management optimisation using a simulation approach and new modern tools, such as the digital factory mentioned above.

As Amorin-Loper et al. [1] mentioned, warehouse and distribution warehouses are critical to supply chains and present a nonnegligible share of operating costs. The cited authors in their research demonstrated a three-step methodology based on simulation, optimisation, and event-based simulation to analyse and realise experiments with warehouse layout and storage issues to improve picking performance. Burinskiene et al. [2] investigated warehouse processes to improve efficiency and warehouse processes by reducing travel time and order picking. The authors proposed a mathematical model and realised a discrete event simulation study. Another interesting study about the combination of the simulation approach and warehouse issues solution is presented by the authors Ganbold et al. [3], who developed a simulation-based optimisation method for improving the warehouse service level. Vieria, et al. [4] developed a simulation model generator in their case study to help a specific company reduce costs regarding time and space in its warehouse. Bučková et al. [5] described the topic of warehouse design using a computer simulation approach in their research paper. The authors used a dynamic simulation in warehouse design as an application in their research. Peixoto et al. [6] showed the ability of discrete simulation techniques to support the method. Their research showed that using simulation allows the assessment of the impact of new sorting equipment and helps test different warehouse management systems and strategies in natural conditions. The authors, Hsieh-Tsai et al. [7], researched the effect of the order-picking system's performance on a warehouse system. The authors used a software eM-plant for simulation and analysis, which presented a design of warehouse database development with the minimum overall travelling distance, warehouse layout, picking route planning, etc. Hietasari et al. [8] emphasised the importance of warehouses in the 4.0 industry era as an essential in the supply chain competition. They presented a conceptual framework that will be required in designing a warehouse management system by analysis of the essential aspects and implemented the strategies first-in-first-out (FIFO) and first-expired first-out (FEFO) based on the idea that these strategies may occur in managing warehouses and create added value toward lean warehousing.

But nowadays, building a modern warehouse that can work in a dynamic global supply chain environment is essential due to solid competitiveness. Therefore, developing a quick and practical design for the warehouse and implementing logistics processes in warehouses is necessary. The current trend is based on the possible use of the digital factory concept. As Kuhn mentioned [9], the digital factory concept can offer an integrated approach to enhance the production engineering processes. Within this concept, the simulation and simulation approach is a key technology. According to the author Arndt. [10], the digital factory means general digital support of the process chain from the stage of development to the final production with the help of virtual working techniques. Buckova et al. [11] presented the idea of a digital factory as the most progressive approach to a complex, integrated product design, production processes and a company's logistics system. Tong et al. [12] presented an understanding of digital factories by implementing an automated warehouse that integrates enterprise resource planning and warehouse management systems in their research. As they mentioned, the manufacturing execution system is the brain and core of a sustainable digital factory. Kihel [13] presented another exciting research on the collaboration or connection of warehouse issue solutions and digital factory concepts. The researcher presented a methodology for the digital transition of warehouse management. As mentioned in the study, the ideas of Industry 4.0, digital factories, and the digitalisation of warehouse operations propose practical solutions to meet market requirements and apply new technologies of the 21st century.

As mentioned in the previous part of this chapter, the effective way to optimise the warehouse management system is to collaborate with a simulation approach and the idea of the digital factory. Hovanec et al. [14] presented the concept of a digital factory and simulation approach to increase the efficiency of the production process, reduce production time and increase overall productivity. Authors Guizzi et al. [15] presented interesting research to define an integrated parametric simulation model for the production and maintenance process by the philosophy of Industry 4.0 and digital factories. The authors used a system dynamics approach to simulate the system's nonlinear behaviour. For example, the authors Yildiz et al. [16] presented the concept of a digital twin-based virtual factory and its architecture based on modelling, simulation and evaluation of production systems. This research also demonstrated how a digital twin-based virtual factory can support factory lifecycle processes. Hovanec et al. [17] pointed to the practical application of the selected simulation software in the digital factory. They emphasised the importance of simulating the entire flow of materials, storage, and production processes as critical components of the digital factory industry. In their research study, Gagliardi et al. [18] developed a discrete event simulation model of the logistics operations at an actual high throughput warehouse which handles more than 12 million cases annually. Their research also pointed out the economic benefits of this approach.

One of the leading simulation solutions in the industry is the Tecnomatix Plant simulation program (after this, referred to as "TPS"). TPS is an object-oriented 3D program used for the simulation of discrete events. It allows the quick and intuitive creation of realistic, digital logistics systems and thus tests the systems' properties and optimises their performance [19].

COMPUTER SIMULATION IN THE FIELD OF DIGITAL FACTORY

As a scientific method, computer simulation is closely connected to Industry 4.0. It affects a wide range of business processes, including logistics. It is also used in areas for which it was unusable until recently. Today, however, computer simulation has far greater possibilities and is open to another field of application.

With the development of Industry 4.0, the computer simulation method is used in addition to production and logistics in other business areas, such as storage. It helps to effectively implement a wide range of storage processes, warehouse operations, and effective handling equipment and improves the overall functioning of warehouse processes.Effective implementation of storage processes within industries is currently a critical factor in the competitiveness of every successful company. Nowadays, computer simulation is already an integral part of warehouse logistics and an essential part of a digital factory. Digital factory is a general term that includes a complex network of digital models, tools and methods. The goal of such a factory is primarily the creation of integrated planning within the framework of individual business processes. The information obtained makes planning and improving individual business processes possible.

The main goal of the case study was the design of the model and the ongoing evaluation of the logistic performance, which the simulation will determine. For analysis, the digital enterprise is divided into four parts: part of the production process or representing a specific logistics framework. All parts describe the individual blocks with working names that are used in the creation of the model. The effort was to separate sections into specific process actions where it is possible to apply simulation. For successful data collection, exact parameters are entered into the individual inputs in process times and volumes of entities passing through the given part of the model. The complexity of the model is also supported by the programming language in which auxiliary methods are defined. The model specifies, for example, variable process times at the production stations, management of personal transporters, warehouse management support, and graphic representation of process cycles. Figure 1 presents warehouse logistics, and Figure 2 presents the factory's digital model's main lines and subassembly lines.

Modelling of the storage process in the warehouse

The storage and processes in the storage have flow characteristics. The warehouse layout has static properties, representing the rack type of storage. In the case study, the shelf has a capacity of ten storage positions. The models are represented by a ´´buffer´´ block with a letter and a number. The area of the shelving units is in four aisles due to compliance with the FIFO principle. To support this method, eight operational areas (four areas for storage and four areas for unloading) are created in the model. The ``Track'' blocks representing the paths are displayed in the simulation environment. Figure 3 presents the storage model in the realised case study.

	string 1	string 2	string 3	string 4
1	A1	A_1_1	Part1	U_1
2	A1	A_1_2	Part1	U_1
3	A1	A_1_3		U_1
4	A1	A_1_4		U_1
5	A1	A_1_5		U_1
6	A1	A_1_6		U_1
7	A1	A_1_7		U_1
8	A1	A_1_8		U_1
9	A1	A_1_9		U_1
10	A1	A_1_10		U_1
11	A2	A_2_1	Part2	U_1
12	A2	A_2_2	Part2	U_1
13	A2	A_2_3		U_1
14	A2	A_2_4		U_1
15	A2	A_2_5		U_1
16	A2	A_2_6		U_1
17	A2	A_2_7		U_1
18	A2	A_2_8		U_1
19	A2	A_2_9		U_1
20	A2	A_2_10		U_1
21	A3	A_3_1	Part3	U_1
22	A3	A_3_2	Part3	U_1
23	A3	A_3_3		U_1

Figure 1. Warehouse logistics in the model of the digital factory

	string 1	string 2	string 3	string 4	integer 5	string 6
1	Part1	L_1	A1	2	0	U_1
2	Part2	L_1	A2	2	0	U_1
3	Part3	L_1	A3	2	0	U_1
4	Part4	L_1	A4	2	0	U_1
5	Part5	L_1	A5	2	0	U_1
6	Part6	L_1	A6	2	0	U_1
7	Part7	L_1	A7	2	0	U_1
8	Part8	L_1	A8	2	0	U_1
9	Part9	L_1	A9	2	0	U_1
10	Part10	L_1	A10	2	0	U_1
11	Part11	L_2	B1	2	0	U_2
12	Part12	L_2	B2	2	0	U_2
13	Part13	L_2	B3	2	0	U_2
14	Part14	L_2	B4	2	0	U_2
15	Part15	L_2	B5	2	0	U_2
16	Part16	L_2	B6	2	0	U_2
17	Part17	L_2	B7	2	0	U_2
18	Part18	L_2	B8	2	0	U_2
19	Part19	L_2	B9	2	0	U_2
20	Part20	L_2	B10	2	0	U_2

Figure 2. Factory's digital model's main lines and subassembly lines

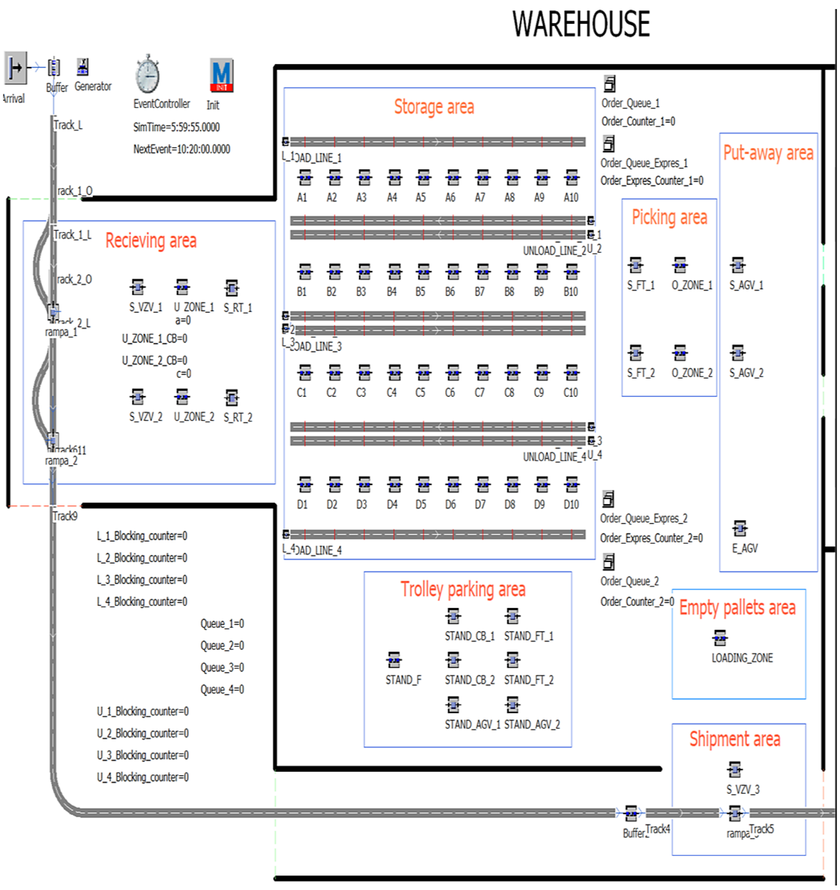

Figure 3. Model of the storage

Each road storing parts is assigned a "station" block with working names: L_1, L_2, L_3, L_4. With the help of these blocks, it is possible to monitor the occupancy of individual aisles with shelves and the associated blocking of separate blocks or FLTs collision. The methods handle the assignment of FLT with cargo to a specific aisle, where the material has a defined warehouse position, to the extent that these places in the model are not connected with joints.

To simulate the process time of removing the containers from the reception area, another ´´station´´ block named S_RT_1 and S_RT_2 is added to the model. These blocks serve as a starting point for linking unloading processes with storage. A pair of tables is implemented in the model to distribute stock items into individual cells.

Figure 4 presents the warehouse system of item registration. Methods are the critical point of correct tabulation. The first method writes the safety stock of materials right when the simulation starts. The second method records the volumes of materials during the stocking process. Individual columns contain the following values:
- shelf name,
- the name of the cell on the shelves,
- the name of the material in the given cell,
- the name of the output block on the given path

Fixed materials are allocated for individual shelf cells, so from the given table, we can find out in advance how many of the given materials we have available. For simulation purposes, individual materials are named as "Part," and a number is assigned. The simulation works with forty different materials.

Figure 5 (table put-away) characterises inventory management in models. Its creation also determines specific routes for FLT movement along the model and the allocation of material to a given shelf. Writing to the tables is handled using the methods executed during storage and container removal from the warehouse. With the help of the table, the actions of the methods intended for storage and removal:
- name of the material,
- entrance block to the warehouse aisle,
- name of the predefined shelf,
- number of pallets of insurance stock,
- initial status,
- exit block from the warehouse aisle.

After finishing the container unloading process to the buffer belonging to the given ramp, the first method is started, which determines the material storage method. The first step is to remove the material from U_ZONE_1, then the process enters the Put-Away table and sets the cursor to the first row and first column. The next step starts a cyclic condition that asks: Is the name of the material identical to the position in the table where the cursor is set? If not, continue moving

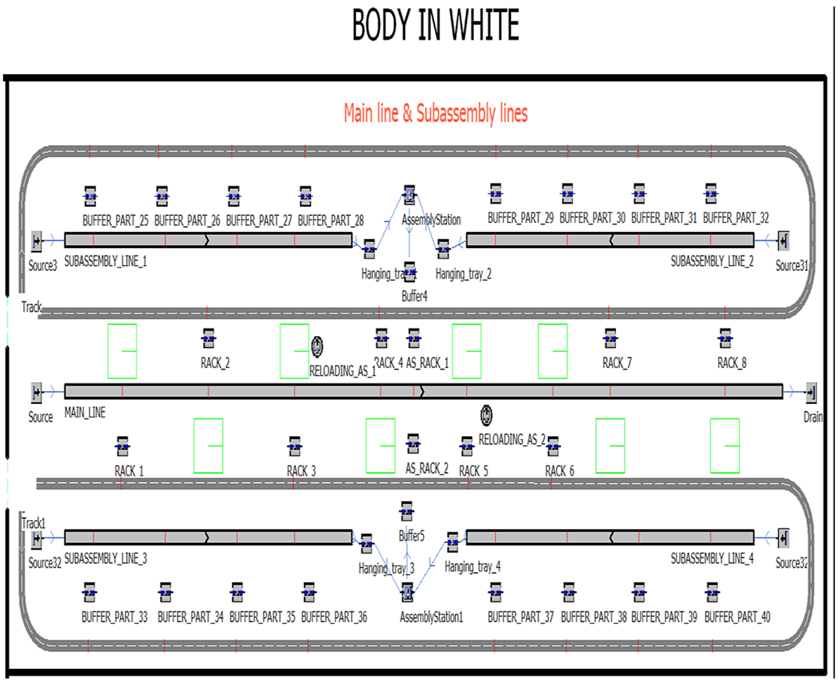

Figure 4. Warehouse system of item registration – output from the simulation software

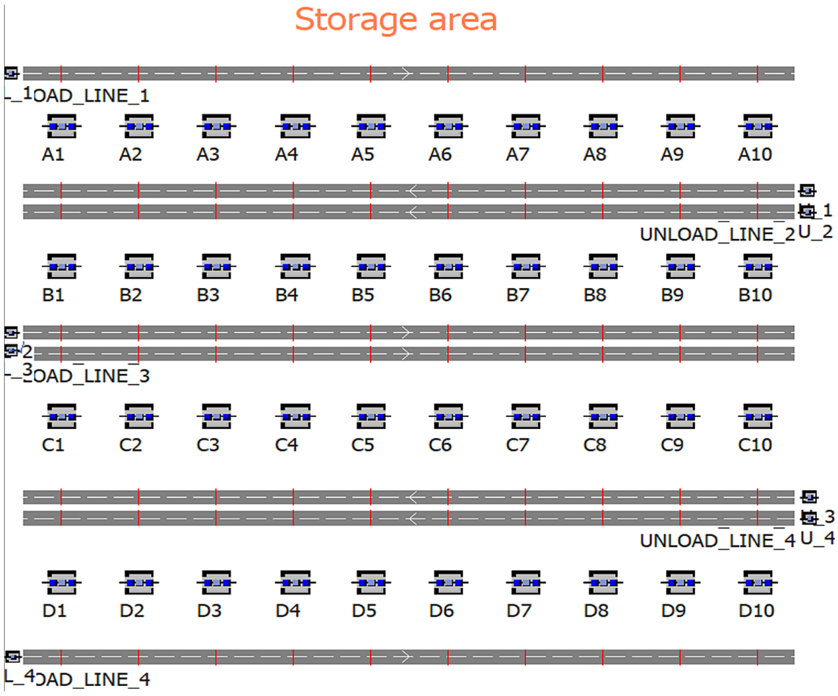

Figure 5. Put-Away – output from the simulation software

the cursor until it is set to the correct line. This condition is simulated in the model due to adequately identifying the material to be transferred to the warehouse. Figure 6 presents the cyclic condition of the material identification.

After the containers are removed from the pre-reception area, the FLT moves based on a cyclic condition to the desired path in the model. There is a modelled sensor on all warehouse shelves. A method is inserted into this sensor that recognises and compares the name of the material in the FLT, the information about the assigned name of the shelf, and instructions on how to stop the FLT. Once the FLT is in the correct location, the method executes the command to store the material in the rack cell. For the transparent records of materials, it is necessary to convert the name of the material into the warehouse table; another method takes care of that. Figure 7 presents the cyclic condition for the evidence of the material in the warehouse management system.

After completing the stocking, the FLT returns to U_ZONE_1 and takes more material. If U_ZONE_1 is empty, the method asks: Is U_ZONE_2 occupied? If yes, send the FLT and start the stocking process. If it is not, send it back to the opinion for FLT. A unique method called ``Init'' is also modelled in the simulation

```
var i : integer
U_ZONE_1.cont.move(@)
PUTAWAY.setcursor(1,1)
for i := 1 to PUTAWAY.ydim
    if @.cont.name = PUTAWAY[1,PUTAWAY.cursory]
        exitloop
    else
        PUTAWAY.cursory := PUTAWAY.cursory + 1
    end
```

Figure 6. Cyclic condition of the material identification

```
if @.POSITION = true
    @.stopped := true
    wait 60
    WHM.setcursor(1,1)
    WHM.find(@.BUFFER)
    for i := 1 to 10
        if WHM[3,WHM.cursory] = ""
            WHM[3,WHM.cursory] := @.cont.name
            exitloop
        else WHM.cursory := WHM.cursory + 1
        end
    next
    @.cont.move(str_to_obj(@.BUFFER))
    @.LOADING := false
    @.POSITION := false
    @.backwards := true
    @.stopped := false
end
```

Figure 7. Cyclic conditions of the material evidence in the warehouse management system

environment. This method is always executed at the beginning when the simulation is started. All conditions and commands the user wants to set at the beginning of each repeated simulation period are inserted into this method. For the warehouse area, the insurance stock setting for all types of materials is included in the simulation. The insurance stock (Table 1) is defined so that the smooth flow of processes in the production part of the hall is ensured and that, during the simulation, they do not build up over the state of the materials or overfill the warehouse capacity.

SIMULATION EXPERIMENTS

The parts of the case study are simulation experiments with the created model. To determine

Table 1. Safety stock on the production lines

Title of the material	Number of pallets	Number of pieces in the pallet	Title of the material	Number of pallets	Number of pieces in the pallet	Title of the material	Number of pallets	Number of pieces in the pallet	Title of the material	Number of pallets	Number of pieces in the pallet
Part 1	4	40	Part 11	3	38	Part 21	2	450	Part 31	5	16
Part 2	3	50	Part 12	6	20	Part 22	2	2160	Part 32	6	16
Part 3	4	30	Part 13	2	1800	Part 23	2	450	Part 33	5	16
Part 4	2	70	Part 14	6	20	Part 24	2	2160	Part 34	5	16
Part 5	2	50	Part 15	3	200	Part 25	5	18	Part 35	2	59
Part 6	4	30	Part 16	3	200	Part 26	4	25	Part 36	5	19
Part 7	2	70	Part 17	6	16	Part 27	2	66	Part 37	2	130
Part 8	3	38	Part 18	6	16	Part 28	2	70	Part 38	2	130
Part 9	2	90	Part 19	5	18	Part 29	2	66	Part 39	5	19
Part 10	2	90	Part 20	4	25	Part 30	2	70	Part 40	2	59

the optimisation elements, it is necessary to point out the current state and present the extracted data from the simulation. As the model becomes more complex, one element is defined from each analysed part, which has the most significant potential to evaluate the simulation. The time study is performed during a sixteen-hour working simulation.

1st Experiment

The first Experiment aims to determine the optimal number of forklift trucks (FLT) for loading and unloading trucks. Optimally used technology in the natural logistics system presents adequately used financial resources for its management. The ideal condition for every logistics object is using technology for 100% of the operating time. In this simulation study, two FLTs are used for truck unloading and one FLT for loading empty containers.

- Data used for the 1st Experiment:
- number of operating equipment, 3 FLTs,
- number of unloading ramps: 2,
- number of loading ramps: 1,
- number of tracks: 24,
- truck unloading time 40 min,
- truck loading time 30 min.

The results of the first simulation experiment (Figure 8) indicate that the FLTs needed to be fully utilised. All three FLTs were not used for 14 % of the working time (column 4). Because the truck arrival time windows are fixed, the lack of efficiency in the service equipment's actual number can be deduced. This state points to an unbalanced ratio between service equipment and work tasks. A parameter change during the simulation period was proposed to improve the current state. One FLT simulates the following state determined only for truck unloading, and the second FLT for cumulative function (Figure 9).

Graph of the 1st simulation experiment – column 0 (Figure 9) with the modified parameters, shows 33% of operating hours, where both techniques are fully utilised. Compared to the first part of the Experiment, it is determined that the operation of three pieces of service equipment is economically disadvantageous in this case. The simulation experiment also confirmed the unloading of all planned LKW (Lastkraftwage - truck) during the simulated time without any delay at the unloading or loading ramps.

The following table (Table 2) shows the input and optimised data for the 1st Experiment. The data show that operating vehicles decreased from 3 FLTs to 2 FLTs.

The results indicate the possibility of increasing the use of FLT capacity while there is no increase in time, costs, or vehicle unloading. In the way described, the simulation model contributed to reducing transaction costs when carrying out loading operations, reducing the binding of financial resources, and increasing the efficiency of the logistics process.

2nd Experiment

The second simulated Experiment monitored the material flow from the warehouse to the

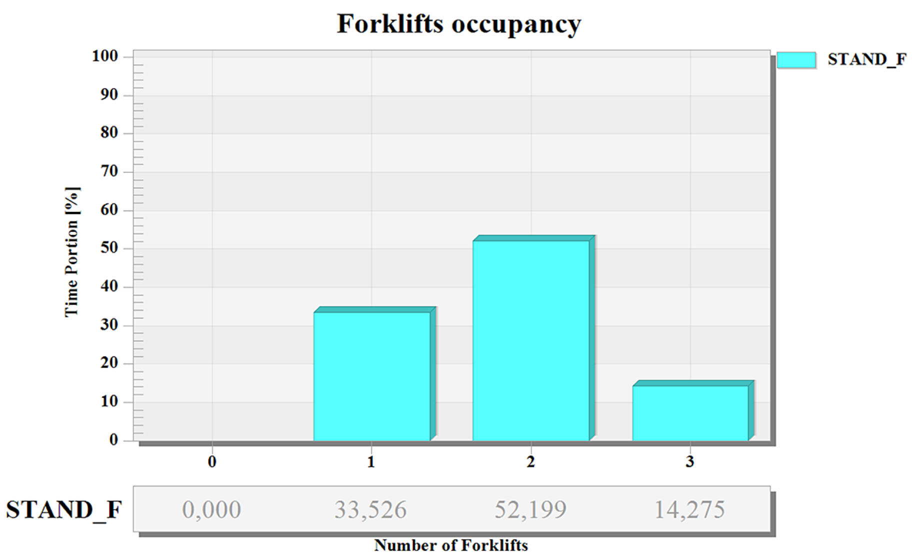

Figure 8. Utilisation of three FLTs

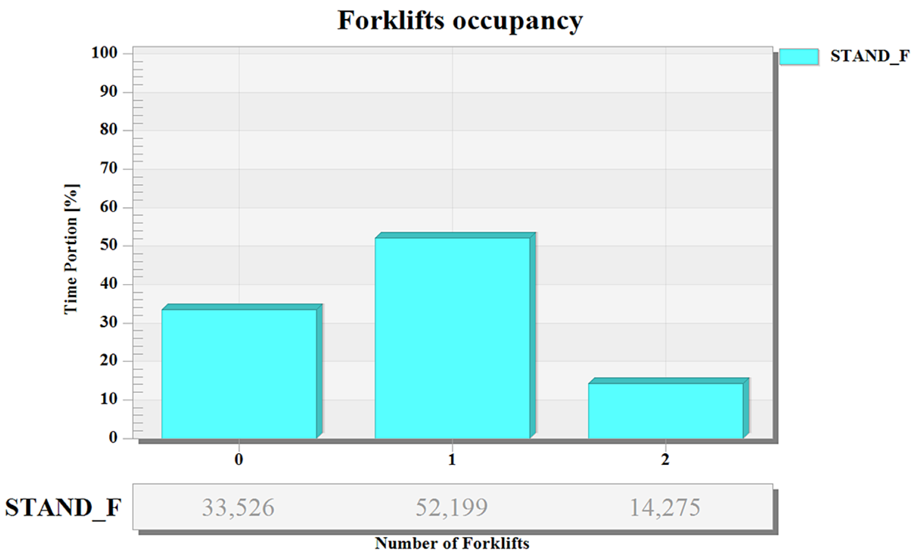

Figure 9. Utilisation of 2 FLTs

Table 2. Comparison of input and optimised data

Parameter	Data used for the 1st Experiment	Optimised data
Number of operating techniques	3 VZV	2 VZV
Number of display ramps	2	2
Number of loading ramps	1	1
Number of trucks	24	24
Truck unloading time	40 min	40 min
Truck loading time	30 min	30 min

Table 3. Distribution of material in the storage – original state

Material name	Position in warehouse	Material name	Position in warehouse
Part 1	A1	Part 21	C1
Part 2	A2	Part 22	C2
Part 3	A3	Part 23	C3
Part 4	A4	Part 24	C4
Part 5	A5	Part 25	C5
Part 6	A6	Part 26	C6
Part 7	A7	Part 27	C7
Part 8	A8	Part 28	C8
Part 9	A9	Part 29	C9
Part 10	A10	Part 30	C10
Part 11	B1	Part 31	D1
Part 12	B2	Part 32	D2
Part 13	B3	Part 33	D3
Part 14	B4	Part 34	D4
Part 15	B5	Part 35	D5
Part 16	B6	Part 36	D6
Part 17	B7	Part 37	D7
Part 18	B8	Part 38	D8
Part 19	B9	Part 39	D9
Part 20	B10	Part 40	D10

production. This model considered this flow to be the ability to remove materials continuously. The ideal situation in this system is if there is no mutual blocking of CB (forklift truck with extendable lifting device). This Experiment aims to determine the current state and propose an alternative with better operating efficiency. The following table characterises the material distribution in the warehouse used for this Experiment (Table 3).

Figure 10 presents the blocking of the routes in the warehouse determined for material removal. The results show 36 cases (column 4) where 2 CBs are in one lane and blocked each other. This fact can lead to delays in material removal from the warehouse and decrease the effectiveness of the examined logistics system.

The second Experiment includes modifying the existing warehouse material layout to find

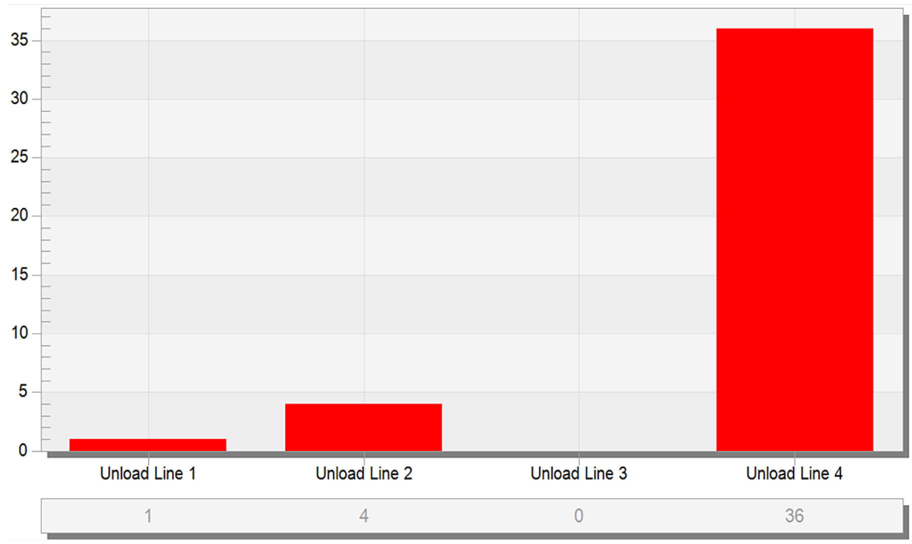

Figure 10. Blocking of CB – original state

Table 4. Distribution of materials in the warehouse – optimised status

Material name	Position in warehouse	Material name	Position in warehouse
Part 1	A1	Part 21	C1
Part 2	A2	Part 22	C2
Part 39	A3	Part 23	C3
Part 4	A4	Part 24	C4
Part 5	A5	Part 14	C5
Part 6	A6	Part 26	C6
Part 7	A7	Part 33	C7
Part 8	A8	Part 34	C8
Part 9	A9	Part 29	C9
Part 10	A10	Part 30	C10
Part 11	B1	Part 15	D1
Part 12	B2	Part 32	D2
Part 13	B3	Part 27	D3
Part 25	B4	Part 28	D4
Part 31	B5	Part 35	D5
Part 16	B6	Part 36	D6
Part 17	B7	Part 37	D7
Part 18	B8	Part 38	D8
Part 19	B9	Part 3	D9
Part 20	B10	Part 40	D10

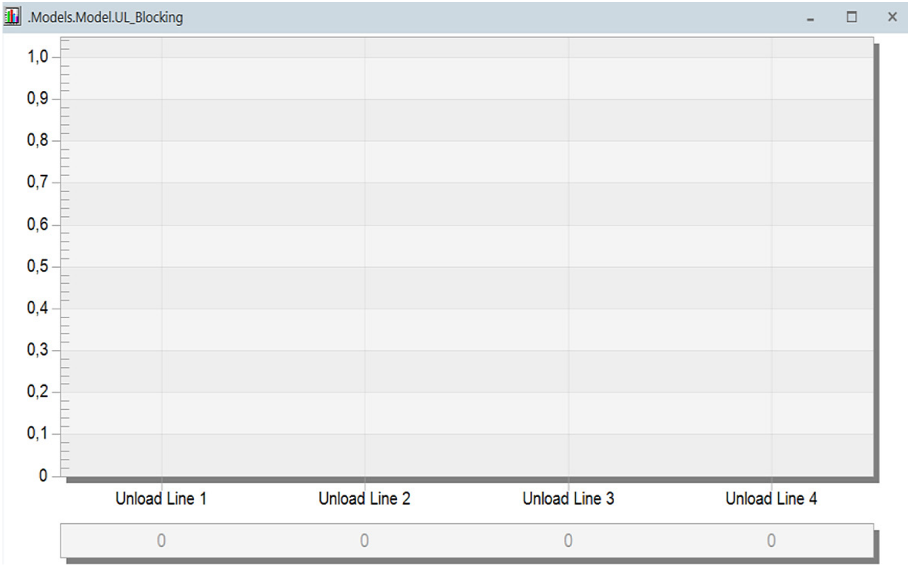

Figure 11. Blocking of CB – optimised state

an optimal alternative for a continuous flow of materials. The following table (Table 4) represents the proposed distribution of materials in the warehouse. The simulation was realised after the material distribution process in the warehouse. It presented the absence of blocks in the warehouse routes. This setting is ideal, as the throughput in the warehouse is ensured at 100% (Figure 11).

Applying the simulation model eliminated the bottleneck when the material flow was not blocked. Through optimization, a smooth production process flow was achieved, downtime costs were reduced, and the efficiency of transport equipment was increased. The obtained results can be used to adjust the production cycle to improve productivity.

CONCLUSIONS

The study focused on modelling and simulating a production hall connected to the warehouse. This study aims to realise simulation experiments on an authentic digital factory model to demonstrate the advantages and use of simulation in warehouse management. The results of these simulations should provide evidence of how simulation can contribute to optimising warehouse operations management, improving material flow and reducing costs within a digital factory. Such an approach can ultimately lead to a better understanding and better warehouse management.

This study used computer simulation as an optimisation element in the concept of Industry 4.0 with the help of the Tecnomatix Plant Simulation program. The first Experiment demonstrated the advantages of simulation in determining the optimal number of forklifts for efficient warehouse operation. The simulation clearly showed that reducing the number of carts from 3 to 2 significantly improved efficiency and used resources economically, with three carts being unnecessarily unused during 14% of the working time.

The second experiment focused on optimising the material flow from the warehouse to production and successfully identified the problem of forklift trucks blocking each other in storage routes. Reorganising the warehouse and changing the distribution of materials eliminated these blockages, which positively affected the flow of production processes.

The benefits of the simulation in warehouse operations and logistics are irreplaceable. Simulation enables detailed analysis and testing of various scenarios and strategies without actual costs and risks. Tecnomatix Plant Simulation is an effective tool for building a digital factory model and performing simulation experiments. Its functions and flexibility enable accurate and reliable simulations that use top simulation technologies to identify and solve critical problems in warehouse processes and logistics. This knowledge undoubtedly improves digital enterprise efficiency and competitiveness in today's dynamic and competitive market environment. The case study aimed to present the application possibilities of computer simulation on the specific examples in the actual conditions. Computer simulation must become a tool used daily. Further research will be directed to increasing efficiency by creating universal blocks for developing simulation models within the expansion of digital factory applications.

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