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APPLICATION OF VIRTUAL PRODUCTION TO UPGRADE INDUSTRIAL PRODUCTION UNITS

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Abstract

Our research work involves the study, analysis and modernisation of the production line of a company that has been operating with traditional systems for a long time with unchanged principles. The paper highlights the use of virtual production as a tool for modernising the company's production processes, providing a comprehensive understanding of its characteristics, advantages and positive impact on process development. The scientific article, after an overview of a selected real production process, describes the steps to build a digital twin for the implementation of virtual manufacturing. It explains in detail the different features and the results obtained in the Tecnomatix Plant Simulation modelling environment used to build the model. After evaluating the simulation, the paper examines the current state of the real process and its overall tool efficiency, and based on the conclusions drawn, it presents a way forward for the development of the production line and the possibilities for further research.

Keywords*: virtual production, Industry 4.0, Tecnomatix Plant Simulation, digital twin, simulation.*

1. Introduction

Today, products are manufactured all over the world. In the industry, we can distinguish between two types of manufacturer based on their digital readiness. Today's start-ups are starting from a completely digital base. In their design process, they place great emphasis on embedding innovative approaches and carefully developing manufacturing strategies. In contrast, the other group is made up of factories that have been operating on unchanged principles for decades and whose outdated production lines are less adaptable. A major obstacle to the development of these firms is that their production systems are difficult to adapt to modern technologies. However, the objective is the same in both cases, to produce as many high-quality consumer goods as possible in as short a time as possible.

Our research aims to support the production of such an old-style factory, which only partially exploits the potential of Industry 4.0, by using virtual manufacturing tools. Our aim is to modernise a selected production line of a plant by means of a digital twin built in a simulation software, which will allow us to improve the development of the company.

2. Virtual commissioning

2.1. Definition

Virtual commissioning is the process whereby production is simulated in a virtual environment using a computer program before a real system is installed (**Fig. 1**). Commissioning is the most time-consuming part of the process of setting up a production unit, and around 70% of system errors can be detected at this time, which can be costly to correct in real life, in addition to many man-hours. Thus, the main function of virtual commissioning is to detect design and assembly errors early and correct them before implementation. **[1]**

2.2. Relevance nowadays

Industry 4.0 and advanced computing have led to the emergence of virtual manufacturing. The basic idea is that market needs can be met quickly and efficiently by integrating the manufacturing of products into a virtual environment using simulation models. The use of simulation supports the improvement of production proceedings and helps to increase the competitiveness of firms. Improving production techniques and increasing productivity are increasingly becoming objectives for which virtual production can be the perfect solution.

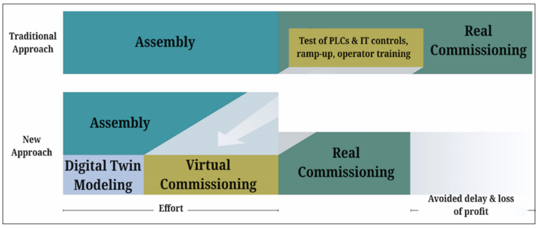

Fig. 1. *Production with and without virtual commissioning.* [1]

3. Virtual production

3.1. Advantages

Virtual manufacturing technology plays an increasingly important role in industry and has many advantages. Through its digital twin architecture, it can be used to design new production systems or improve existing ones. Simulation allows the pre-analysis of production without interfering with real processes. Testing is carried out first of all to verify the perfect functioning of each production unit, the manufacturability of the products, and then to evaluate the functionality and efficiency of the production process. The early detection of faults reduces the time needed to start production and reduces downtime, and the modelling avoids the need for post-production system redesigns. Although there is a significant outlay to buy the right software, the cost of debugging and rework is reduced, so the investment will pay for itself over the years. In the event of a redesign, the large amount of data collected from the digital twin will allow for the most targeted decision-making. [2]

3.2. Proposing research carried out on Industry 4.0

There is a significant, growing amount of research on the opportunities offered by Industry 4.0, and it offers opportunities for researchers wishing to explore the topic in more depth.

The design principles of the fourth industrial revolution are described in William de Paula Ferreira et al. [3] According to a study by János Simon, VR technology in human resource education enables the training of industrial workers in a digital factory. [4] Raimund Wegener et al. use the tool of simulation to virtualise the production of yarn and wool fibres. [5] Eric VanDerHorn et al. have developed a generalised definition of the concept of digital twin. [6]

The publication by Kuldeep Kumar Verma and Vivek Babele favours the use of simulations and explores the various potentials of Tecnomatix Plant Simulation. [7] Karolina Bendowska and Przemysław Zawadzki have used Tecnomatix Plant Simulation to create the most accurate simulation model possible of an automated assembly line in their research. [8]

The above studies have inspired our research project, and we have benefited from many of the theories discussed, which we have tried to incorporate into our work.

3.3. Application in the automotive industry

One of the biggest users of virtual manufacturing is the automotive industry. The latest achievement of the BMW Group is the construction of a virtual factory, the real construction of which, in a unique way, only takes place after the modelling and simulation. The precise, high-quality preparation created in NVIDIA's Omniverse system enables virtual vehicle production of NEUE KLASSE models before the start of actual series production.

4. Tecnomatix Plant Simulation

In our research, we created a virtual model of a real production unit using Tecnomatix Plant Simulation. The program is a discrete, event-driven process simulation tool in which the digital twin of manufacturing and logistics processes can be quickly built and tested (Fig. 2). Its most common

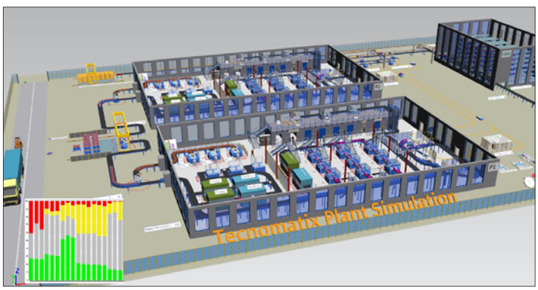

Fig. 2. *Plant Simulation model in practice.* [9]

application is the simulation of flow processes. The excellent possibilities offered by the software allow real production processes to be accelerated and product development to be made more efficient.

5. Actual production process of the company

The company sponsoring the research project is a leading multinational company in the production and packaging of liquid cleaning products. During several site visits, we had the opportunity to carry out an in-depth analysis of the production line of the plant, which manufactures a specific product. We monitored the part of the production process of the selected detergent where empty plastic bottles start on an assembly line, pass through various stations to reach marketable state and the packaging of the products begins (Fig. 3).

Although the production system is in continuous use, there are some downtimes due to the age of the production line and inaccuracies in the production units. Virtual production is a possible solution to avoid these.

6. The constructed digital twin

To implement virtual production, we have transferred actual production processes into a virtual environment. Using Tecnomatix Plant Simulation software, we created a process-level digital twin that accurately represents the original manufacturing system (Fig. 4 and 5). The modelling was based on production data for the year 2022 collected by the company. Several additional data elements were also added to the digital model, such as the length and speed of the conveyor belts and the number of products manufactured per minute at each station. These parameters were accurately observed and measured, then converted into input data for the simulation software. In the following, we describe the different parts of the model, which will be shown to illustrate how they correspond to reality.

6.1. The actual production line in the Tecnomatix Plant Simulation software

In the first step of the simulation, empty bottles are delivered in bulk from the bottle warehouse to the first station via a gravity dispenser. The bottles are then placed on their bases and transported in rows on two conveyor belts, which are finally combined into a single row by a merge conveyor.

Fig. 3. *Manufacturing system of the production process.*

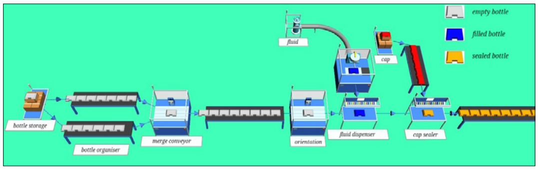

Fig. 4. *The constructed virtual model I.*

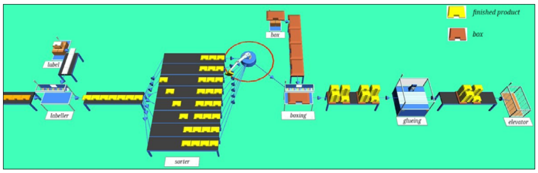

Fig. 5. *The constructed virtual model II.*

The longitudinal dimensions of the conveyor belt in the model are accurate to the original by centimetres. In addition, their speeds were determined and converted from BMP, the unit of measurement for the original units, to m/s, which can be set in the model.

The conveyor following the merge conveyor guides the bottles to the orientation station. Orientation is a unit that turns the bottles at a 30-degree angle in the correct direction while creating a gap the size of the filling head between them. These operations prepare the filling of the liquid. The filling device dispenses 0.75 litres of chemical into each bottle with a tolerance of ± 1%. This process is interpreted as the assembly in the model.

For both the stations and assemblies, we have provided processing time, which is the time a given unit spends on one or more products, depending on the definition.

This is followed by the secure sealing of the filled bottles. The cap sealing station wraps the caps, which arrive based on the principles of gravity, around the bottles by applying a pulling force of 40 N. The next conveyor ensures the material flow between the cap sealing and labelling assemblies. At the labelling station, the sealed bottles wrap their labels around themselves, which are properly secured by adhesive bonding. The finished products, already filled and with the overwrap, are conveyed via an assembly line to the sorting unit, where a pneumatic conveyor sorts them into 2 × 4 = 8 lanes, and palletising begins.

The boxing operation is performed by a TT manipulator with pneumatic gripping in 8.3 seconds. 40 products can be lifted at a time, which are then placed in 4 × 5 arrangements (4 columns, 5 rows), simultaneously filling 2 boxes.

When the boxing is finished, an assembly line leads to the station where the boxes are glued. The last step is to securely seal the cartons, which can hold 20 bottles, using adhesive tape, which are then conveyed by a conveyor belt to the packing plant.

Considering the construction of the digital twin, the 3D shape of the elements has been replaced by their functions, and Plant Simulation does not handle the 3D objects representation perfectly, so the simulation is based on workstations that are only illustrative but perform the same tasks as in reality.

6.2. Refinement of the simulation model

In order to make the digital twin even more representative of reality, we have summarised the malfunctions of the components based on the production data of the company. As shown in **Table 1**, errors due to inaccuracies in the operation of individual stations caused significant downtime for the company in 2022. In order to reflect these losses in the simulation results, we have assigned these operating errors to the units. For each unit in the model, one can set the availability it can operate at relative to the simulation time. The annualised operation error of each station is represented in the simulation as an availability.

Table 1. *Production line failure of 2022*

Production line item	Error caused (minute)	Availability (%)
Bottle organiser	3 838	98.97
Merge conveyor	1 326	99.65
Conveyor	676	99.94
Orientation	1 694	99.56
Fluid disperser	7 830	97.95
Cap sealer	2 766	99.28
Labeller	3 048	99.20
Sorter	1 309	99.56
Robotic arm	1 519	99.60
Boxing	13 904	96.36
Glueling	970	99.75

6.3. Evaluating the simulation model

The results of the analyses carried out on the model reflect a realistic simulation (**Fig. 6**).

The results show that the individual sub-processes are not properly coordinated and the system needs to be modernised. While the merge conveyor almost completely blocks the production process at the beginning of the line, the boxing and glueing stations are waiting for products for more than 90% of their operating time. Based on 2022 data for the production system, the current efficiency of the production process (OEE)

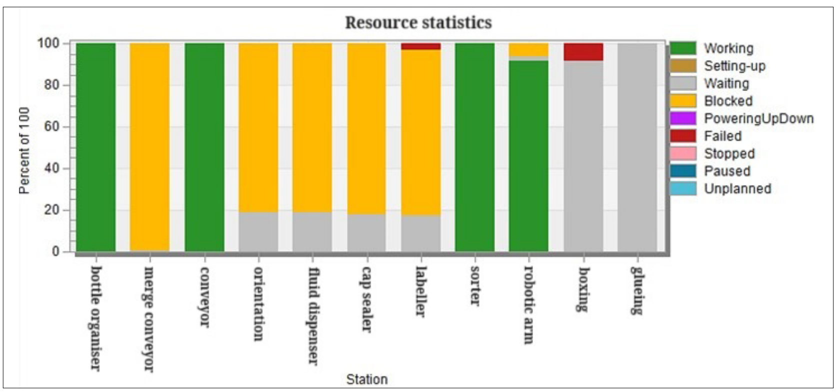

Fig. 6. *Current production line resource statistics.*

is approximately 72%, which is calculated as follows:

planned production time:	382 022 min
actual production time:	274 785 min
total downtime:	62 987 min
planned uptime:	0.0038 min/unit
quantity of units produced:	60 448 969 unit

Waste unit is not an issue as all raw materials are recyclable.

$$A = \frac{274\,785}{382\,022\ -\ 62\,987} \cdot 100 = 86{,}13\% \qquad (1)$$

$$P = \frac{60\,448\,969\ \cdot\ 0{,}0038}{274\,785} \cdot 100 = 83{,}59\% \qquad (2)$$

$$Q = \frac{60\,448\,969}{60\,448\,969} \cdot 100 = 100\% \qquad (3)$$

$$OEE = (0{,}8613 \cdot 0{,}8359 \cdot 1) \cdot 100 = 71{,}99\% \qquad (4)$$

The above shows that the production system needs to be improved. A major increase in overall equipment efficiency is necessary for the development of the company.

7. Opportunities for research development

The research has succeeded in creating a digital twin of an industrial production line, which was analysed using the company's 2022 data. Further development plans for the project include the suggestion of modifications based on the results obtained, to achieve a significant increase in the efficiency of the process and maximum operational capacity of each element.

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