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NAVIGATING HYPER-INDIVIDUALIZATION: BUILDING RESILIENCE SYSTEMS THROUGH PROCESS SIMULATION

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Purpose: The primary objective of this research is to provide empirical evidence supporting the application of simulation as a strategic tool for bolstering operational resilience.
Design/methodology/approach: This paper employs the simulation and the case study method.
Findings: Simulation is a pivotal tool for manufacturers seeking to enhance operational resilience. Through meticulous analysis of real-world production systems and translating these insights into sophisticated simulation models, manufacturers can significantly bolster their resilience. This methodology enables organizations to anticipate and mitigate potential disruptions, thereby ensuring uninterrupted operations and maintaining a competitive edge.
Practical implications: This study proposes simulation research as a means of enhancing performance and informing investment choices. Notably, simulation modelling fosters a proactive perspective, allowing organizations to not only endure and recover from adversity but to also emerge fortified and reinvigorated, rather than simply reverting to pre-crisis states.
Originality/value: The article underscores the strategic significance of simulation modelling in fortifying an organization's operational resilience.
Keywords: operational resilience, simulation, production, material flow, organizational improvement.
Category of the paper: Research paper.

1. Introduction

The confluence of global challenges, including the COVID-19 pandemic (Schleper et al., 2021), the Russian invasion of Ukraine (Srai et al., 2023), escalating trade tensions, and the European Union's concerted drive towards a sustainable and competitive economic model, has underscored the imperative for contemporary organizations to cultivate a robust capacity for resilience (Banaszyk, 2022).

What is more, resilience is also one of critical aspects of Industry 5.0, driving the trend of hyper-individualization by allowing for the production of goods tailored to specific user needs. This rising demand for personalized products introduces the need for developing flexible systems for manufacturing (Khan et al., 2023; Maddikunta et al., 2022). Thus Industry 5.0 prioritizes flexibility to enable hyper-individualization. The growing trend of individualization necessitates a paradigm shift in manufacturing, moving beyond rigid production lines towards adaptable and responsive systems that can cater to diverse customer preferences (Koren et al., 2015). Building resilience through increased flexibility is a key part of Industry 5.0. (Sheffi, Rice, 2005). Given these circumstances the Fifth Industrial Revolution might heavily rely on simulations for its success (Asmaa Seyam May EI Barachi, Mathew, 2024; Maddikunta et al., 2022).

The task of constructing business workflows within a dynamic environment presents a formidable challenge. Beyond a comprehensive understanding of the workflow itself, it is imperative to contemplate its broader context and the prerequisites for its effective functioning and the realization of its intended outcomes (Malega et al., 2022). The management of operations during periods of upheaval becomes a formidable undertaking. A multitude of potential actions must be carefully considered. Simulations, facilitating an understanding of the implications of potential decisions prior to their implementation, empower the strategic planning of material flow processes to optimize efficiency while accommodating the unique requirements of individual production environments. Through this endeavor, it is feasible to devise actions that can be successfully executed even in the face of unforeseen circumstances.

2. Literature review: resilience and simulation

2.1. Resilience

The notion of resilience has been examined within three primary disciplines of the social sciences: sociology, psychology, and economics. To date, research has investigated organizational resilience from various viewpoints. Hepfer and Lawrence (2022) posit three primary conceptualizations of resilience:

- absorption and recovery: This perspective emphasizes the sustained functioning of an individual or system in the face of adversity, without necessarily reverting to a previous state or progressing to a new one;
- anticipation, coping, and adaptation: This conceptualization highlights reactive and adaptive behaviors, suggesting that resilience involves the ability to anticipate challenges, cope effectively, and adapt to changing circumstances;
- bouncing back and bouncing forward: This framework differentiates between returning to an original position (or ‘bouncing back’) and positive development (or ‘bouncing forward’) following a setback.

A recent study by Hepfer and Lawrence (2022) identified three key dimensions of organizational resilience:

- strategic resilience refers to an organization's ability to foresee and counteract potential threats that could jeopardize its long-term goals and overall strategy;
- operational resilience concerns an organization's capacity to respond effectively to adverse events that affect the entire entity and may disrupt its ongoing operations;
- functional resilience pertains to a specific organizational department or process, with the majority of existing research concentrating on localized disruptions within the supply chain and information systems sectors.

The notion of resilience within supply chain management (SCRES) is a comparatively recent development. Rice and Caniato's (2003) work represents an early contribution to this field. A notable advancement was made by Christopher and Peck in (2004), who introduced a preliminary framework for supply chain resilience (SCRES) (Shi et al., 2023). They defined SCRES as the capacity of a system to revert to its original condition or progress towards a more advantageous state following a disruption, thereby establishing a fundamental definition for future research.

As outlined by Hohenstein et al. in (2015), supply chain resilience is defined as the ability of a supply chain to be prepared for unforeseen risk events, to respond and recover promptly from potential disruptions, and to return to its original state or even advance to a new, more advantageous position (Asmaa Seyam May EI Barachi, Mathew, 2024). It is noteworthy that both disruptions in general and, specifically, the COVID-19 pandemic have spurred increased academic and practical attention on supply chain resilience as a means of gaining a competitive edge (Irfan et al., 2022).

Resilience, within the context of this study, is defined as the adaptive capacity to mitigate the likelihood of unforeseen internal or external disruptions, to anticipate and prepare for such occurrences, to react promptly to them, to contain their spread, to recover from their effects, and ultimately to reinstate the original state or transition to a more advantageous position (Ali et al., 2017; Gunasekaran et al., 2015; Maryniak et al., 2021; Ocicka et al., 2022; Szymczak, 2015).

2.2. The essence of simulation

The term 'simulation' originates from the Latin language (simulo, similis, similo, similar, simulacrum) and signifies: to feign, represent, imitate, mimic, similar, similarity. Its significance can be assessed in diverse contexts. In previous scientific research and the accompanying literature, this issue has been examined in the following contexts (Diakun, 2023):

- in the context of a research method (simulation method),
- in the context of a technical-organizational undertaking (simulation study, simulation project),
- in the context of a computational process (simulation run).

Table 1 presents the definitions of simulation.

Table 1.
Simulation Definitions

Item	lowercase letters
G. Gordon	a method of problem-solving that monitors temporal variations in a dynamic system model
T.H. Naylor	a numerical technique for conducting experiments on certain types of mathematical models, which use a digital machine to describe the behavior of a complex system over a long period
G.S. Fishman	collection of techniques that, when applied to the study of a discrete-event dynamical system, generates sequences called sample paths that characterize its behavior
J. Winkowski	time-ordered reproduction of consecutive process runs
G.W. Evans, G.F. Wallace, G.L. Surtherland	the process of chronologically constructing a sequence of state representations, forming a state trajectory
R.F. Barton	the targeted operation of a subject system model
J. Banks, J.S. Carson II, B.L. Nelson, D.M. Nicol	the imitation of the operation of a real-world process or system over time
S. Robinson	experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system
M. Beaverstock, A. Greenwood, W. Nordgren	to experimentally reproduce the behavior of a real-world system through the use of a model

Source: Developed on the basis of: (Banks et al., 2010; Barton, 1974; Beaverstock et al., 2017; Evans et al., 1967; Fishman, 2001; Gordon, 1974; Naylor, 1975; Robinson, 2004; Winkowski, 1974).

Considering the preceding points, it is evident that computer simulation, as defined by Latuszynska (2011) and Mielczarek (2009), constitutes:

- an experimental methodology,
- a numerical technique,
- an implementation on dynamic models that mirror real-world systems,
- a tool for comprehending the temporal behavior of the system under analysis.

Simulation studies, combining knowledge from statistics, computer science, and the specific domain, are currently being employed to develop cyberphysical supply chains (Fig. 1).

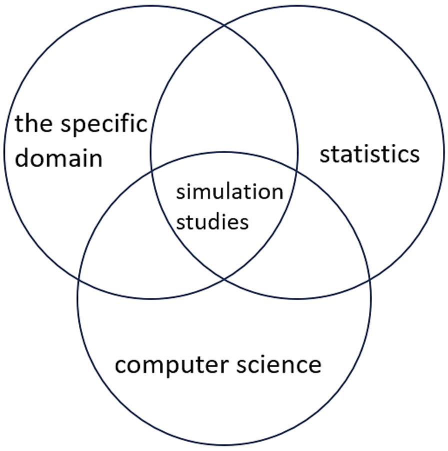

Figure 1. Cross-disciplinary nature of simulation methods.

Source: Developed on the basis of Diakun (2023).

Consequently, this approach may enhance the resilience of these chains operating within a network of intricate and dynamic process and economic interdependencies (Nowicka, Szymczak, 2020). In contemporary research, computer software is typically employed to execute simulations. The sequential stages within simulation studies are commonly delineated as steps or illustrated graphically in the form of block diagrams within relevant academic literature. The simulation study comprises several distinct stages. Firstly, the problem to be addressed is clearly defined. Subsequently, a specific goal or objective is established for the study. The scope of the investigation and the required level of detail for the simulation model are then determined. Input data is collected and analyzed to inform the model construction. A simulation model is subsequently developed, followed by rigorous verification and validation processes. A simulation experiment is meticulously planned, executed, and analyzed to extract meaningful data. Finally, comprehensive documentation is prepared, and the simulation results are effectively implemented.

Simulation constitutes a compelling analytical instrument owing to its multifaceted benefits (Fishman, 1981). Simulation studies are a valuable tool for investigating complex processes, both existing and hypothetical. They are particularly useful for analyzing hazardous processes or those involving unavailable resources. When analytical methods fail to provide solutions for real systems, simulations can offer a means of understanding their behavior and dependencies. By creating virtual representations of these systems, simulations can facilitate decision-making and promote a deeper understanding of their inner workings (Jackson et al., 2024). Moreover, simulations allow for the manipulation of time, enabling users to accelerate or decelerate processes to study their dynamics in detail. Analyzing the relationships between system inputs and outputs, as well as the sources of variability, is a key benefit of simulation studies. The ability to replicate simulations multiple times provides researchers with a robust foundation for drawing conclusions. Furthermore, the simulation's measurement error can be significantly reduced. The study's continuity is also ensured, allowing for repeated and complete interruptions to conduct analyses and then resume, with the capability of examining all states.

Additionally, simulation computations are more cost-effective and time-efficient than direct observations.

2.3. Research gap

Among the three facets of organizational resilience, operational resilience has received the least attention within the fields of management and organizational studies (Holgado et al., 2024). Essuman et al. (2020) assert that our academic comprehension of operational resilience is restricted, given that the preponderance of research focuses on the firm and supply chain levels.

3. Discussion

In examining the evolution of production paradigms, a noteworthy shift emerges: the transition from mass production to mass customization, ultimately culminating in the nascent concept of mass individualization. While all three paradigms share the core functions of design, manufacturing, and sales, they diverge in two key aspects: the sequencing of these operations and the level of customer influence within the purchasing process. A key feature of the mass-individualization paradigm is active customer involvement in product design. This presents a unique challenge for manufacturers. Customers can now personalize their products by selecting from a range of certified modules offered by various vendors, or even design and build their own modules. Companies implementing product portfolio control strategies must strike a delicate balance between the variety of offerings and the resulting operational complexity (Buzacott, Mandelbaum, 2008; Koren et al., 2015).

This strategic equilibrium achieves a balance between optimized operational efficiency, profitable customer relationships, enhanced product quality, and reduced costs. Research conducted by Desai, Kekre, Srinivasan, Meeker, Meyer, and Mugge demonstrates that the introduction of additional product and service variants can lead to increased profitability (Desai et al., 2001; Meeker et al., 2009). However, the research also highlights the critical importance of effective management in mitigating the complexities associated with such diversification. Without appropriate control measures, the potential benefits of offering a wider range of products and services may be compromised (Meyer, Mugge, 2001).

Today's focus on individualization requires a fundamental change in how things are made. Manufacturers must abandon the limitations of traditional production lines and adopt responsive systems that can meet the diverse needs of their customers. In the analyzed case at the plant in the end of line area (EOL) there are twenty-nine packaging machines arranged in series in two rows opposite each other, with one common pathway used to collect homogeneous pallets with the finished product (Fig. 2). In the place where pallets with finished products are received, just behind the packaging machines, there is so little space that only one forklift can move there without the possibility of turning around.

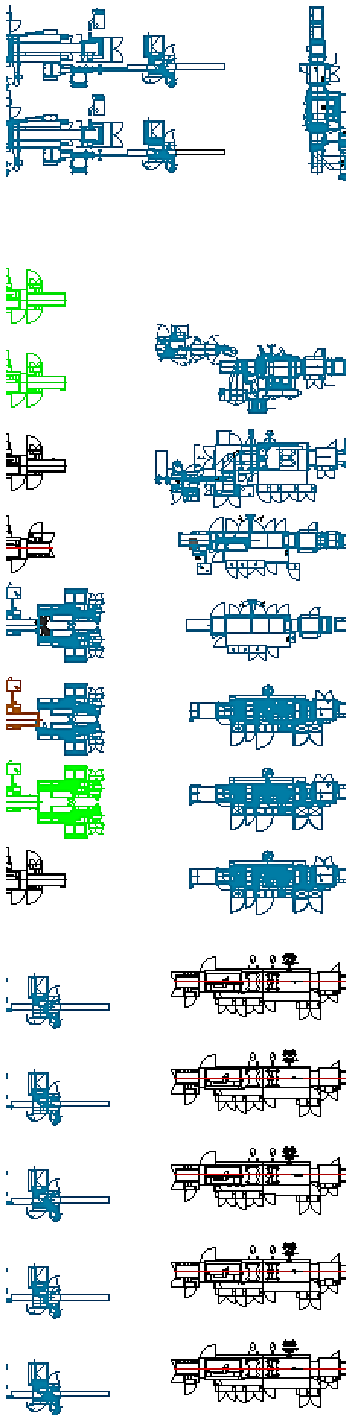

Figure 2. Twenty-nine packaging machines arranged in series in two rows opposite each other, with one common pathway used to collect homogeneous pallets with the finished product.

Twenty-nine packaging machines operate in the plant, staffed by two workers each. One packs the packages into cartons and sends them for sealing and labelling. At the end of the packaging machine, the second operator picks up the cartons and puts the packages on a pallet according to a previously established pattern (Fig. 3). In this variant, a total of fifty-eight employees work.

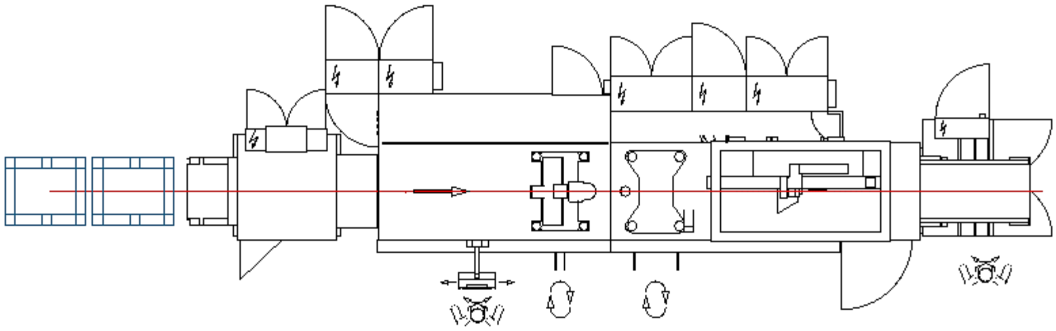

Figure 3. Packaging machine staffed by two workers each.

In the current production variant, there is a situation where the operator has a full pallet with the product, more packages arrive to be placed on the pallet, but the forklift operator cannot collect the pallet with the product due to narrowing the pathway. It is not possible to add a second forklift. This causes downtime and the need to stop packaging machines, and thus reduces the efficiency of the line.

The client stipulated the creation of an internal transportation system within the EOL area designed to maintain uninterrupted process flow, minimize operational disruptions, and avoid bottlenecks. Additionally, the system should reduce material losses, equalize workload across workstations, and expedite customer order fulfillment.

Considering the first proposed solution, a conveyor can be installed behind the packaging machines (Fig. 4). This conveyor will then direct product packages to another hall for sorting.

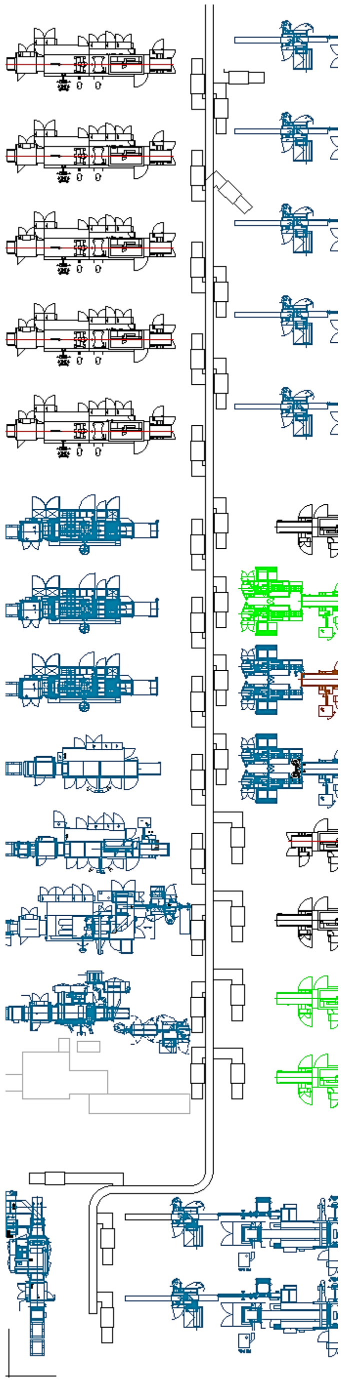

Figure 4. A conveyor installed behind the packaging machines.

In this dedicated sorting area, employees will take the packages off the conveyor and place them on pallets.

This solution necessitates twenty-nine factory floor workers and twenty sorters in a separate hall, connected by a conveyor.

The next considered solution variant suggests, similarly to the previous case, adding a conveyor behind the packaging machines and directing products through this conveyor to another hall. However, in the second variant, the variety of offerings products are redirected to a conveyor where they are automatically detected and sorted using a vision system that recognizes packages and sends to previously defined storage fields.

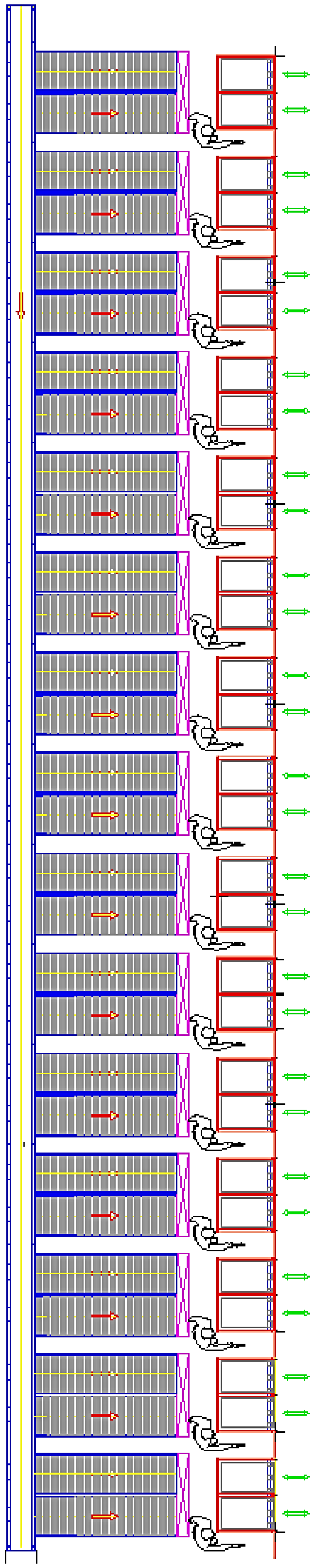

Figure 5. Automatic Detection and Sorting System with Vision Technology.

After the product reaches the storage place, the product is taken from conveyor and placed on a pallet by a factory floor worker (Fig. 5). This solution necessitates twenty-nine factory floor workers and fifteen sorters in a separate hall, where collision-free collection by several forklifts is possible.

The last scenario assumes, similarly to the previous case, adding a conveyor behind the packaging machines and directing products through this conveyor to another hall. However, in the third variant, the variety of offerings products are redirected to a conveyor where they are automatically detected using a vision system that recognizes packages and then, unlike the previous variants, sent to previously defined places (pick points) for collection by the robot.

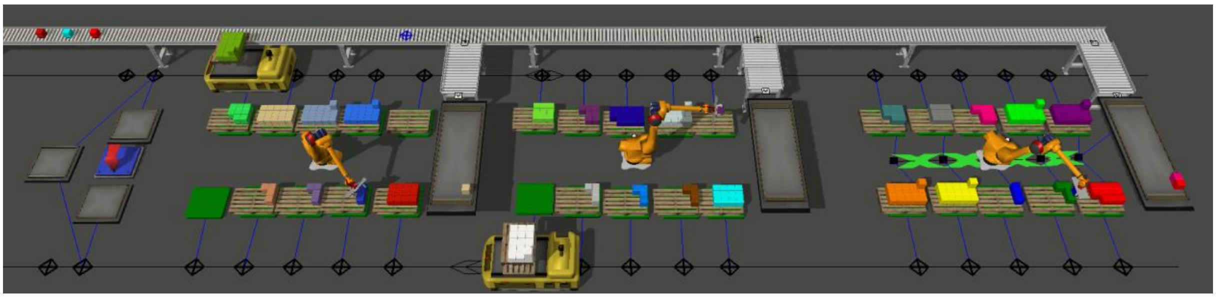

Figure 6. The developed investment scenario.

The entire system uses six collection points and three robots (Fig. 6). Each robot supports two collection points. After the product reaches the appropriate collection point, the product is picked up from the conveyor by the robot and placed on a previously defined pallet. Each robot places products on ten pallets. After filling the pallet with the appropriate number of packages, one of two transport cars (T-car) arrives, depending on the location of the pallet (Fig. 7). This solution necessitates twenty-nine factory floor workers, no sorters are needed.

Two pallets fit on a single T-car. The empty pallet comes first. The second place is intended for downloading a full pallet. After the robot has completed the entire pallet, a T-car is called.

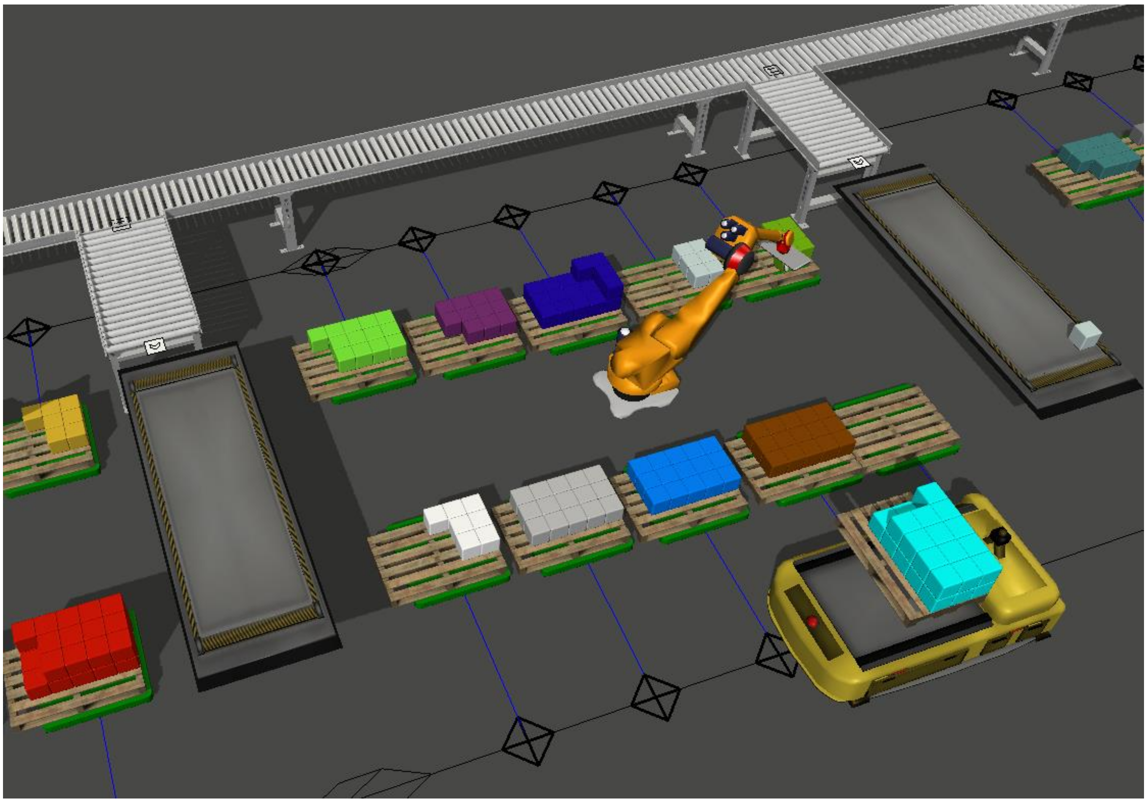

Figure 7. T-car.

It starts from a parking space, where a full pallet is always delivered and an empty one is picked up. Once the T-car arrives at the location with the full pallet, the pallet is loaded onto the T-car. The T-car replaces the full pallet with an empty one and returns to the parking space. The cycle is then repeated. After unloading the full pallet from the T-car, it is transported via a system of conveyors to the finished products buffer, then retrieved by the operator for redirection to the finished products warehouse. Empty pallets are delivered to the system via destackers and then transported via a conveyor system to the T-car. In order to achieve greater efficiency of the entire system, two T-cars are used, located on the left and right side of the pallet loading system, each adapted to unload/load full pallets and load/unload empty pallets.

The developed investment scenario presenting the new concept along with the method of its implementation was presented to the investor in material flow simulation software FlexSim. The FlexSim language leverages the combined power of 3D animations and graphical representations, enhancing its visual appeal for users. FlexSim empowers users to develop and utilize dynamic 3D animation models, providing a comprehensive library of standardized elements to streamline the modelling process. This library comprises a rich set of elements including: sources, sinks, combiners, robots, processors, workers, conveyors. Every element within FlexSim is defined by a set of characteristics, including properties, states, events, appearance, and logic. Properties store user-defined input values, whereas states represent dynamic values that can change throughout the simulation. With the model finalized, FlexSim empowers users to explore various scenarios, enhancing decision-making. These scenarios allow different parameters to be analyzed simultaneously and their combined effects on the system to be observed (Poloczek, Oleksiak, 2023).

The simulation model, built within the FlexSim software environment, replicated the architectural layout of the company's production facility. Through a meticulously detailed description, the machine layout achieved realistic dimensions that seamlessly integrated with transport routes and storage fields. Drawing upon the floor plan of the production hall, the specific locations of operational workstations were identified and subsequently incorporated into the model, utilizing the previously established dimensions. Figure 9 shows the input data defining the parameters for quantifying the final result and determining average throughput ranges.

	No	Cartons/hour	Min number of boxes on a pallet	Number of pallets per hour	Cardboard every sec	Cardboard every min
Row 8	21	48.49	28	1.73	74.25	1.24
Row 9	27	34.15	24	1.42	105.43	1.76
Row 10	29	34.15	24	1.42	105.43	1.76
Row 11	10	19.80	16	1.24	181.77	3.03
Row 12	24	19.80	16	1.24	181.77	3.03
Row 13	20	19.80	16	1.24	181.77	3.03
Row 14	19	19.80	16	1.24	181.77	3.03
Row 15	7	9.56	16	0.60	376.53	6.28
Row 16	2	11.61	20	0.58	310.08	5.17
Row 17	1	10.24	24	0.43	351.43	5.86
Row 18	22	48.49	28	1.73	74.25	1.24
Row 19	16	34.15	24	1.42	105.43	1.76
Row 20	26	34.15	24	1.42	105.43	1.76
Row 21	28	34.15	24	1.42	105.43	1.76
Row 22	18	19.80	16	1.24	181.77	3.03
Row 23	17	19.80	16	1.24	181.77	3.03
Row 24	14	19.80	16	1.24	181.77	3.03
Row 25	3	17.07	24	0.71	210.86	3.51
Row 26	8	9.56	16	0.60	376.53	6.28
Row 27	4	11.61	24	0.48	310.08	5.17
Row 28	23	48.49	28	1.73	74.25	1.24
Row 29	5	19.12	12	1.59	188.27	3.14
Row 30	15	34.15	24	1.42	105.43	1.76
Row 1	25	34.15	24	1.42	105.43	1.76
Row 2	13	19.80	16	1.24	181.77	3.03
Row 3	12	19.80	16	1.24	181.77	3.03
Row 4	11	19.80	16	1.24	181.77	3.03
Row 5	6	19.12	16	1.20	188.27	3.14
Row 6	9	9.56	16	0.60	376.53	6.28
Row 7	30	700	28	25	5.14	0.09

Figure 8. Input parameters.

By feeding the FlexSim system with input data, their impact on the output data is observed (Fig. 10). Dashboards generated based on dynamic process parameters provide insights into system utilization (Fig. 9).

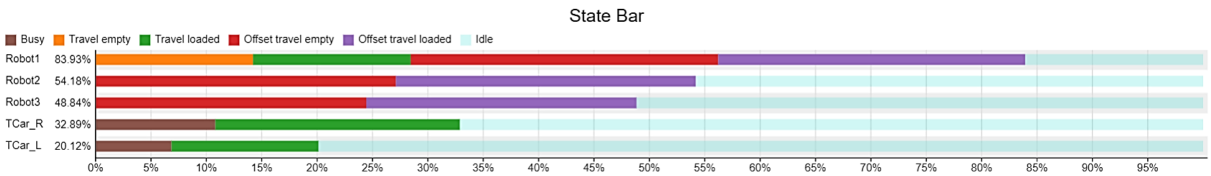

Figure 9. Optimization of infrastructure and resources.

In subsequent iterations, in accordance with the frequency of occurrences and the established pattern, the system assigns pick points to which the products are sent. It then determines the place where the robot built the pallet cargo unit and then the appropriate T-car for pickup.

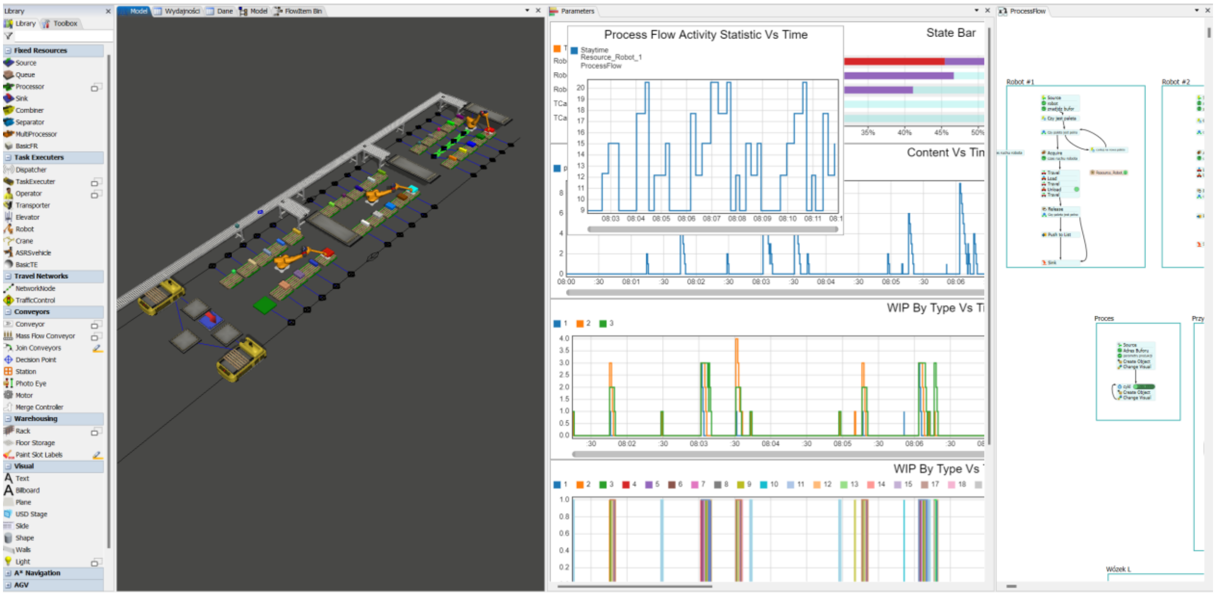

Figure 10. Verification of process and operations.

A shift towards adaptable and responsive systems is crucial to meet the diverse preferences of today's consumers. The choice of FlexSim simulation software for developing a solution was based on the potential advantages it could offer at various stages of the business project implementation (Beaverstock et al., 2017). These benefits were anticipated to contribute to feasibility assessment, cost reduction, detailed design refinement, and the validation of existing processes and operations.

Business process simulation studies provide valuable tools for problem-solving and investment decision-making. The requisite model accuracy varies contingent upon the particular task, whether it be production simulation, production process optimization, or the resolution of economic challenges(Eberle, 2020; Lidberg et al., 2020).

The proposed solution sought to:

- optimize process continuity by eliminating downtime, disruptions, and bottlenecks,
- minimize losses throughout the production process,
- balance workload distribution across workstations,
- reduce process variability and ensure consistent performance,
- accelerate order fulfilment by decreasing the overall processing time.

Given the aforementioned assumptions, a comprehensive analysis of the entire system was required, encompassing potential scenarios and interrelationships. The system should not be regarded as a collection of autonomous subsystems but rather as an integrated entity (Goldratt, Cox, 2016). A holistic perspective enables a thorough understanding of how interconnected elements contribute to the overall system's efficacy (Hamrol et al., 2015).

The primary objective of any organization is to achieve success. However, in any business endeavor, limitations can hinder the system from reaching its optimal performance. These constraints act as bottlenecks, restricting the system's throughput (Bilinovics-Sipos, Reicher, 2023).

The Theory of Constraints (TOC) acknowledges the interdependence of various elements within a system, analogous to the chain network theory (Moore, Scheinkopf, 1998), wherein the overall system's strength is determined by its weakest component (Hamrol et al., 2015). TOC concentrates on identifying and addressing these constraints, ensuring a harmonious flow of materials, products, information, and human resources. This approach empowers organizations to optimize their effectiveness, ultimately leading to enduring success.

4. Conclusions

The convergence of mass customization presents a transformative opportunity for the manufacturing sector, enabling the production of highly personalized goods. However, the successful realization of this vision hinges upon the implementation of robust and efficient product sorting systems. A three-dimensional model of the actual internal transportation system was developed through simulation, enabling a comprehensive analysis of its operational characteristics. The simulation experiments conducted facilitated the investor's comprehension of the potential outcomes of various decisions prior to their implementation. The "what-if" feature provided valuable insights into viable solutions for recognized challenges. The simulation employed for this purpose evolved into a tool for illustrating how the throughput of the designed system can be modified through iterative computational processes, continuous monitoring of the system, and ongoing interpretation of its behavior.

The article emphasizes the strategic value of simulation modeling in enhancing an organization's operational resilience. By establishing a simulated environment to identify potential vulnerabilities, optimize resource distribution, and devise contingency plans, this methodology empowers businesses to anticipate and mitigate the impact of disruptive occurrences. This proactive approach enables organizations to enhance their resilience and minimize the adverse effects of unforeseen challenges.

This paper advocates for simulation research as a methodological framework to elevate performance and guide investment decisions. Importantly, simulation modeling cultivates a forward-thinking perspective, enabling organizations not merely to withstand and recover from challenges but to undergo transformative evolution, transcending the status quo that preceded such difficulties.

As the need for customization and personalization increases, production system optimization becomes crucial. Simulation offers a cost-effective means of analyzing systems. This approach provides a distinct advantage by enabling the prediction of potential outcomes within the production system, thereby mitigating financial risks associated with actual implementation.

Although the case study has limitations, the results convincingly demonstrate the growing role of business process simulation as a tool for optimizing production systems and effective variant management in the face of the growing demand for customized and personalized products.

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