Assessing the operational performance of an automated distribution center in food and beverage industry

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Abstract: Automated distribution centers play a critical role in ensuring the smooth flow of goods within supply chains. They offer numerous benefits, including reduced operating costs, increased productivity, improved accuracy in building orders, and enhanced traceability of the products. However, designing and validating such facilities can be a complex and time-consuming process, requiring a deep understanding of the underlying operations and their interactions. In terms of cost, automated distribution centers represent approximately 20 per cent of total logistics costs and they are critical to meet customer service requirements. To increase efficiency, space utilization and minimization of waste, many companies are trying to automate their processes. This paper aims to validate the performance of an automated distribution center (warehouse) located in Atlanta (USA) by using discrete-event simulation methodology. This paper focuses on the analysis of the current state of the warehouse by describing the "As-Is" scenario and giving the first evaluation of the entity of the flows within the warehouse. Then, the simulation of the "To-Be" scenario has been assessed to evaluate the design of the newly automated warehouse and by anticipating and solving possible issues that might arise in the implementation phase. According to the findings, the introduction of a new fleet of laser-guided vehicles brings a notable enhancement in overall warehouse efficiency. This improvement was evidenced by notable reductions in average cycle time, travel distance, and the required number of vehicles. The results highlight the positive impact of implementing the discrete event simulation on streamlining warehouse operations and optimizing resource utilization.

Keywords: Supply Chain Management; Discrete Event Simulation Models; Laser-guided vehicles

1.Introduction

Efficient warehouse management is a crucial aspect of supply chain operations (Baker et al. 2007). In terms of costs, these account for about 20 percent of the total costs related to logistics, and also in terms of service level warehouse management is critical to meeting customer demands (Baker et al. 2007, Clemente-Pecho et al. 2023).

Automation appears to be reasonably widespread in large warehouses, particularly about conveyor/sortation, and automated storage and retrieval systems, where these types of equipment appear to be present in more than one-third of large warehouses (Rowley 2000). Warehouse automation is characterized by the direct oversight of handling equipment, facilitating the movement and storage of loads without necessitating human operators or drivers. This definition underscores the fundamental concept of warehouse automation, emphasizing the reliance on advanced technologies and automated systems to streamline material handling processes without the need for manual intervention (Rowley 2000, Tagashira 2022). Warehouse material handling automation refers to the use of technology and equipment to automate and optimize the movement and storage of goods within a warehouse or distribution center. Warehouse material handling automation can also include a wide range of equipment, such as conveyors, sorters, robotic arms, and automated storage and retrieval systems but excludes technology where warehouse operators are still necessary (Baker et al. 2007).

The analysis of data related to the sale of automated materials handling equipment shows steady growth in recent years. The reasons for this steady increase in sales include potential improvements in productivity, order accuracy, reduced space requirements, increased volume capacity, control of inventory and increased customer service (Krishnamoorthy et al. 2021).

Laser Guided Vehicles (LGVs) and Automated Guided Vehicles (AGVs) play pivotal roles in warehouse automation, with LGVs utilizing laser sensors for marker-based navigation on racks and AGVs employing various guidance systems such as magnets, wires, sensors, or cameras embedded in the floor (Moshayedi et al. 2019). Integration of these automated vehicles with Enterprise Resource Planning (ERP) and Warehouse Management System (WMS) brings substantial operational advantages (Nantee and Sureeyatanapas, 2021; Rossi et al. 2017, Amico et al. 2023). Terms like self-guided vehicle, laser-guided vehicle, and guided carts are often synonymous with AGV. Because of their ambiguous definitions, these terms are frequently used interchangeably in both theory and practice (Kopp et al. 2023, Reis et al. 2023). LGVs can be utilized to automate complex warehouses, such as those with single-depth, drive-in, and gravity flow racks, due to the comprehensive control of dispatching and routing by warehouse management software. AGVs are a prominent and emerging technology aimed at enhancing automation in intralogistics. AGVs are autonomously controlled vehicles primarily used for internal material transport (Ferrara et al. 2014).

The ERP system furnishes real-time data on inventory and order status, empowering LGVs and AGVs to make informed decisions (Queiroz et al. 2022). Concurrently, the WMS facilitates precise coordination, directing vehicles to specific warehouse locations and optimizing movements for enhanced throughput while minimizing congestion (Nantee and Sureeyatanapas 2021). This seamless integration not only improves operational efficiency and accuracy but also provides heightened visibility and traceability throughout the supply chain (Nantee and Sureeyatanapas 2021). By enabling the tracking of goods from origin to destination (Amico and Cigolini 2024), the integrated system offers comprehensive oversight, enhancing control over the logistics process. In summary, the synergy between LGVs, AGVs, ERP, and WMS yields significant benefits in streamlining material handling processes and improving overall logistics management (Nantee and Sureeyatanapas 2021).

The primary objective of this paper is to scrutinize and substantiate the design of a warehouse automation solution. The overarching goal is to employ Discrete Event Simulation (DES) tools to investigate how automation can enhance warehouse logistics performance. More specifically, the aim is to assess the potential improvements in warehouse performance. The research objective of the study is to validate the performance of a new fleet of LGVs, evaluate the assumptions made to run different model scenarios, and identify the key factors influencing the fleet's performance under varying conditions such as changes in demand, traffic patterns, and allocation policies. Despite the extensive discussion of the disruptive technologies in the extant literature, this study contributes to academic literature by focusing on the study of a real-life case study in the food and beverage industry. Our contribution is to measure the warehouse automation's solutions after having assessed the sizing of the warehouse. Then we measure the performance of the warehouse in terms of fill factor and saturation. Our contribution to the extant literature concerns the simulation of two real-world extreme scenarios to test the proper sizing and performance of the warehouse.

Positioned within the realm of literature that examines the impact of DES tools on warehouse performance, this paper contributes to the existing body of knowledge by applying these methodologies to a real-world case, namely a warehouse located in Atlanta (USA).

The remainder of this paper is structured as follows: in section 2 a literature review is provided. Section 3 explains the methodology of the study, while section 4 introduces the case study, which represents the kernel of the work. Section 5 describes the model, results and final conclusions are described and discussed in section 6 and 7, respectively.

2.Literature Review

In the exploration of the DES application within the warehousing field, Gagliardi et al. (2007) demonstrated the historical use of DES to validate warehouse operations. This involves evaluating potential alterations in layouts or operations before their implementation. Gagliardi et al. (2007) highlighted the practical application of DES in warehousing, emphasizing its role in objectively assessing and refining operational strategies for improved efficiency and effectiveness. The authors showed that DES is a helpful tool to evaluate the feasibility of their project but research, data analysis and a deep understanding of the system are critical to reduce results variability. Corneal and Melo (2020) and Baker (2004) demonstrated that DES is a useful tool for a preliminary evaluation of a system, but they also focused their attention on building the model in a way that would replicate the reality as much as possible in order to provide valid results.

According to Nantee and Sureeyatanapas (2021) Logistics 4.0 practices yield significant added value across the economic, environmental, and social dimensions of firms' sustainability performance. The authors placed a specific emphasis on the application of AGVs. This underscores how the adoption of advanced logistics practices, particularly through AGV utilization, positively influences not just economic efficiency but also contributes to environmental conservation and social responsibility within the operational framework of companies.

Kłodawski et al. (2017) provided an overview on the issues of warehouse process strategies. This work shows the impact that a Smart Decision Maker - a system or application that makes decisions using advanced information, data, and algorithms - has on the efficiency of every warehouse operation. Being able to track down each single Stock Keeping Unit (SKU) and having real time information regarding the state of the warehouse is critical to improve the efficiency of every single operation of the warehouse (Kłodawski et al. 2017).

The results reported in aforementioned studies are consistent with Dekhne et al. (2019) and Fottner et al. (2021) that address the reasons why a company should automate their processes. Among the reason there are: to overcome the shortage of labour, the rise in e-commerce and, lastly, the important improvement that Logistics 4.0 has brought to the market with new and efficient solutions (Malagón-Suárez and Orjuela-Castro 2022; Tas 2023; Franceschetto et al. 2023). This convergence of perspectives reinforces the idea that automation is increasingly seen as a strategic response to contemporary challenges in the business landscape. As identified by Baker and Halim (2007), since 2000, there has been an increasing investment by companies in automated materials handling equipment. The authors attribute this trend to several key reasons, including increased efficiency, minimized storage needs, expanded handling capabilities, optimized inventory management, and enhanced customer satisfaction. Pustodio and Machado (2020) identified warehouse automation as a strategic necessity for companies to keep up with the rising demand driven by the spread of e-commerce, mass customization, and omni-channel distribution.

Pospisil et al. (2021) explained why a company should not automate, or at least hesitate its warehouse. One prominent factor is the insufficient collaboration within different segments of the same supply chain. It is known how the lack of collaborations between different companies working in the same supply chain can badly influence the performance and therefore offer a bad service to the end customer (Amico and Cigolini 2023; Pospisil et al. 2021; Amico et al. 2022; Rossi et al. 2017). Automation solutions have the potential to enhance performance through improved traceability and awareness of operational flows (Pospisil et al. 2021; Cigolini et al. 2021). Implementing an automated solution might result in a transient period of low productivity of the plant and, above all, for automation to work, collaboration between customers and suppliers needs to happen to make the flows as stable as possible (Pospisil et al. 2021). The other reason highlighted by Pospisil et al. (2021) is the shortage of production of intralogistics solutions. Since many companies are trying to automate their warehouses and facilities, some suppliers are struggling to satisfy the demand and it might happen that between the time a company places an order and the actual implementation of the solution of the selected system, this latter becomes obsolete (Mahroof 2019). According to Baker and Halim (2007), automation can involve flexibility and service level risks, which must be considered during the management phase of the transition to automation. Furthermore, it is necessary to make decisions that take into account various factors, such as integrated decisions between marketing and supply chain factors.

In the light of these considerations, the objective of this study is to provide empirical evidence, using data from a real case study, for the enhancement of warehouse efficiency through the application of DES methodologies and smart decision-making algorithms. The intended contribution is to bridge the gap between theoretical insights reported in the literature and the practical application within the context of the Atlanta (USA) plant, serving as the focal point for this analysis. This research aims to demonstrate the tangible impact of employing DES methodologies and smart decision-making algorithms on real-world business operations.

3.Methodology

In order to validate the performance of an automated distribution center using DES, a real case study has been considered in order to identify a warehouse automation solution to improve efficiency, space utilization and minimize waste. Specifically, the aim of this study is to assess the effectiveness of the facility's layout, and material handling equipment, and to identify potential areas for improvement. To achieve this goal, a data analysis of the facility's operations has been carried out, by collecting and analysing data on key metrics such as order volume, order frequency, and product mix.

Through the establishment of a virtual representation of the facility, DES provides companies with the ability to conduct experiments involving diverse layouts, configurations, and control strategies (Verriet et al. 2013). This virtual experimentation facilitates the observation of how these factors influence critical performance indicators such as throughput, inventory levels, saturation, and fill factor.

The use of DES offers numerous benefits. First, it facilitates cost reduction by identifying inefficiencies in a system and proposing improvements that can lead to financial benefits. Second, DES enables time savings through the rapid simulation of complex systems, allowing for quick testing of various scenarios and conducting what-if analyses (Agalianos et al. 2020). Another advantage is the reduction of risks, as DES can identify potential issues in a system before they manifest, enabling proactive measures to mitigate risks. By harnessing the capabilities of DES, organizations can acquire valuable insights into the dynamics of their distribution centers, enabling them to make informed decisions aimed at optimizing efficiency and overall performance (Ning 2020).

The warehouse analysed in this project is in Atlanta (USA) and it is owned by Alpha, a leader company in the food and beverage industry. Alpha is actively working towards achieving maximum automation in its warehouses located in the United States. To realize this objective, the company has enlisted the support of Beta, an Italian owned company specialized in the development of automated and integrated intralogistics solutions for manufacturers of consumer goods operating in the beverage, food, tissue and other sectors. The scope of the project is to validate the design of a warehouse automation solution applied to Alpha's Atlanta plant using Beta designed DES software package.

Hence, the research methodology used in this study involved a case study approach to validate the performance of a new fleet of LGVs in an Alpha Distribution Center using a DES software. The research design involved the collection of data from multiple sources including Beta, Alpha, the simulation software, and the extant literature review. Data collection methods consisted of interviews, and document analysis. The simulation model was developed using the data collected, and data analysis techniques were used to compare different scenarios and identify key findings. This research methodology was chosen for its ability to provide a rigorous and comprehensive approach to investigating the performance of the new LGVs fleet, and to provide insights into the key factors that influence performance under different scenarios.

4.Case Study

Alpha's plant in Atlanta (approximately 85,000 square meter) handles beverage and food pallets. The warehouse hosts approximately 9,000 different items, in 2022 it received 33,000 orders (inbound) and shipped 29,000 orders (outbound). Atlanta Service Center is currently facing multiple operational challenges. The site is plagued by low service and quality levels, characterized by delayed orders and instances of multiple shipments for the same order. Furthermore, frequent product damages are occurring due to lapses in operator attention and inadequate procedures.

Compounding these issues is a high turnover of labour, resulting in a shortage of experienced workers and subsequently leading to suboptimal performance by the existing workforce. Addressing these challenges comprehensively is imperative for improving overall operational efficiency and enhancing customer satisfaction.

The model was designed to capture the processes and the missions handled by the Beta system, including inbound and outbound flows, material handling automation, and inventory management. By simulating the system under various scenarios, the aim is to identify potential bottlenecks and optimization opportunities and evaluate the performance of the automated solution. The results of this simulation can inform strategic decisions and improve Alpha's ability to meet customer demands efficiently and effectively.

5.The model

In this section, the development and implementation of a DES model to simulate the operations of Atlanta Service Center is presented. The first goal of this study is to understand whether the proposed fleet of LGVs is sized correctly. Then, once the fleet size is validated, multiple scenarios of the system's behaviour have been considered. This model serves as the basis for the analysis, and it is helpful to understand the impact of the new LGVs on the overall performance of the Distribution Center. The products are aggregated by SKU for the purpose of analysis.

Atlanta supply chain handles several different products, which have different storage needs. For this reason, the warehouse employs specific segregation rules - that refers to the process of sorting and grouping incoming goods according to their characteristics such as size, weight, fragility, and storage requirements - for product storage. The hardest segregation in Atlanta supply chain is the separation between refrigerated products and non-refrigerated products. For this reason, there is a section in the facility where the temperature is lower and refrigerated products are stocked. Among non-refrigerated products there is another segregation dedicated to Bag in Box (BIB) products. BIB products are preferentially stocked in their dedicated area, when saturated they are stored in the other Push Back Locations. Moreover, the storage and retrieval happen on the same side of the racking system only allowing Last In First Out (LIFO) policy to be used and each level can be dedicated to a single SKUs. In addition, non-stackable products are preferably stored in Push Back racks, while items labelled with the item type "Allergen" must be exclusively placed on the floor. In conjunction with the aforementioned rules, an additional parameter plays a crucial role in assigning each SKU its dedicated Storage Area, namely the stock threshold. This parameter ensures a balanced distribution of stock across the warehouse, preventing the occurrence of significant imbalances in saturation levels among different storage areas. By incorporating this parameter, the warehouse management system aims to optimize storage efficiency and maintain a well-balanced inventory distribution throughout the facility.

After a deep analysis of the data, March was selected as the reference month of the simulation because, according to the data analysis, it was the busiest month throughout the whole analysed period.

Forty-seven LGVs manage the material flows. These vehicles operate at a speed of 1,600 mm/s on straight paths and 700 mm/s on curved paths. The time required for LGVs to load and unload goods varies depending on the specific interface: (i) Push Back Rack Load/Unload (57 seconds), (ii) Block Storage Load/Unload (20 seconds), (iii) Inbound Conveyor Load (30 seconds), and (iv) Floor Load/Unload Point (25 seconds).

The model outputs encompass various key metrics and visual representations. These include the average cycle time for each type of flow, providing insights into operational efficiency. Additionally, the utilization of LGVs is monitored to assess their efficiency in material handling. The saturation and Fill factor - the ratio between occupied storage positions and locations already partially or totally occupied - of the warehouse are analysed, ensuring optimal space utilization. Graphical representations illustrate the model's behaviour compared to predefined targets, aiding in performance evaluation. Furthermore, a 3D visual representation of the warehouse offers a comprehensive view, enhancing the overall understanding of the system's dynamics and layout.

Several assumptions were considered in the model development. Firstly, the simulation period for both scenarios is set at one week, and it is assumed that the flows, operational policies, and procedures remain constant throughout this duration. In terms of inbound flows, it is assumed that they are evenly distributed among the inbound conveyors. The simulation assumes a consistent operational environment with no unexpected downtime or delays. Charging missions for LGVs are presumed to have uniform durations, and these vehicles are expected to operate at their maximum capacity and speed. The demand for materials is assumed to remain constant throughout the simulation week. Lastly, the layout of the facility is considered static, with no alterations during the simulation period.

6.Results

6.1 Scenario 1

This scenario represents the worst case in which the LGVs have to face the peak flows throughout the whole period and the distribution of the SKUs requests is the same as the data gathered in the data analysis. This configuration brought the model to the limit and the results could not be considered satisfactory.

The subpar performance observed in the DES can be attributed to two primary factors. Firstly, the presence of peak flows consistently throughout the entire simulation week has strained the operational capacity of the system. This sustained high demand has likely led to congestion and inefficiencies in material handling processes. Additionally, specific SKU requests originating from the picking and repack lines have further impacted the performance of the LGVs, introducing variability and potentially disrupting the smooth flow of operations.

This scenario is also helpful to understand the importance of having a balanced warehouse and a clear view of the flows. Right after one day of simulation the Variety Pack lines requests start suffering. Variety Pack are lines that are concerned with creating variety pack packaging, also known as multipacks, bundles individually wrapped products into secondary packaging for customers to buy as a single purchase. This happens because the requests are not in line with the inbound flows and the initial stock of the warehouse and therefore after just a few hours of simulation the requested SKUs cannot be found in the warehouse and other retrievals are made.

The shipments are displayed in Figure 1. As can be seen, the target is 161 pph (pallet per hour) and the system struggles in reaching the target.

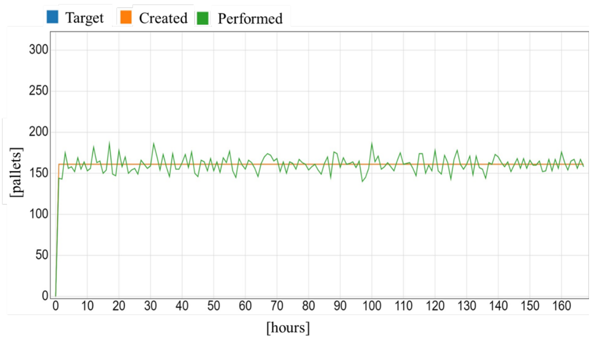

Figure 1: scenario 1 Shipments Target vs Performed

The saturation and fill factor graph is displayed in Figure 2. The graph is consistent with the expectations. The flow diagram representing the peak flows is not balanced: the outbound flows are greater than the inbound flows resulting then in a decreasing trend over time. The inbound flows are consistent with the target of 141 pph and overall LGVs fleet utilization is 94%.

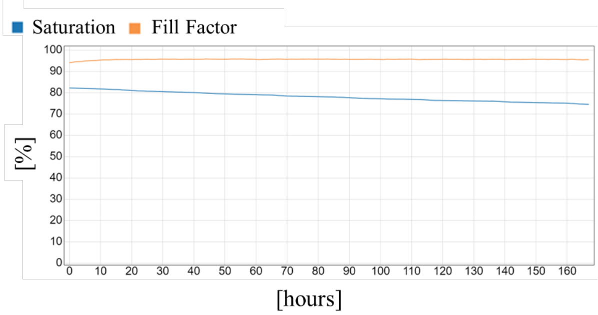

Figure 1: scenario 1 Warehouse Saturation and Fill Factor

6.2 Scenario 2

This scenario represents a better representation of the reality in which the flows decrease during night. The main difference with the first scenario, apart from the different distribution of the shipping flows, is the configuration of the requests from the repack lines. Each SKU had the same probability to be requested from the areas and, above all, always the closest pallet was retrieved. This allowed the model to perform better as displayed in the following figures.

Figure 3 displays the shipments with a different shape. The peak flows are simulated only for 8 hours per day, and this results in a better performance of the model and a better representation of the reality.

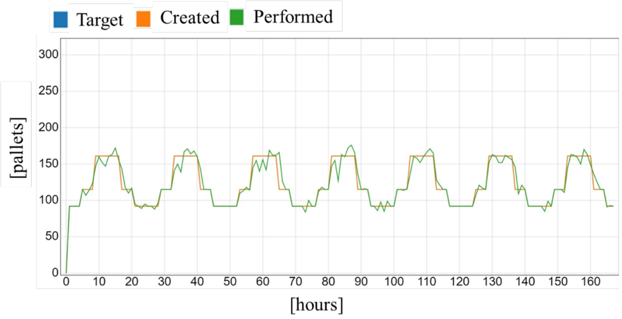

Figure 3: scenario 2 Shipments Target vs Performed

The choice of avoiding considering the popularity of the SKUs in the repack lines requests resulted in a more consistent performance of the LGVs in meeting the target. The main reason behind this improvement is the fact that the requests were created only for SKUs that were present in the warehouse and available.

Figure 4 represents the evolution of the fill factor and the saturation of the warehouse throughout the whole simulation week. Having decreased the shipments helped in having more balanced flows, resulting in a constant saturation of the warehouse. LGVs fleet utilization is 87% and 13% of idle time is an acceptable value that proves the right sizing of the fleet.

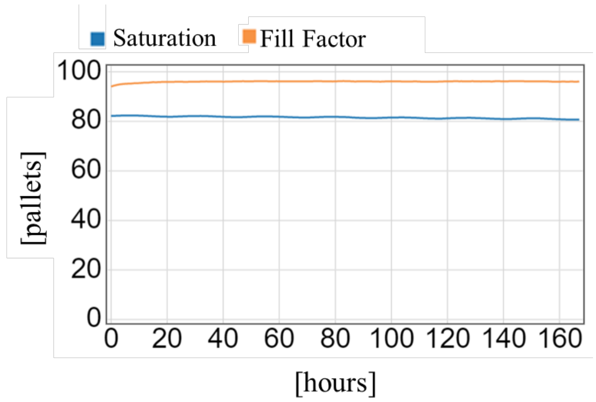

Figure 4: scenario 2 Saturation and Fill Factor

The main difference between Scenarios 1 and 2 was the configuration of the requests made from the picking area and repack lines. The first scenario considered a more realistic situation in terms of requests also involving the percentage of extraction of the SKUs. This made the system slower because of a lack of balance.

It often happened that the SKUs that were requested were stored far away from their destination or not even in the facility and this impacted negatively the results. On top of that, the second scenario had significantly less shipments. As mentioned before, Scenario 1 demonstrated the importance of understanding the flows happening in the warehouse and the critical role that input data plays in the performance of a model. Scenario 2 can be considered a valuable representation of how the system will behave. At the same time, it is worth mentioning that the purpose of the simulation is the evaluation of the system in stressful conditions. Most of the time, the flows will be lower than what simulated.

7.Conclusions

This study aimed to validate a new fleet of LGVs through a discrete event simulation software. This work evaluated the warehouse performance of the "To-Be" scenario in comparison to the existing scenario (As-Is) and, above all, the expected target required by Alpha company. The research objectives were achieved by conducting a comprehensive literature review, designing a simulation model, and analysing the results of different scenarios.

The literature review provided a detailed overview of the current state-of-the-art in warehouse automation and validation using discrete event simulation. The review revealed that simulation is a valuable tool for optimizing warehouse operations, improving efficiency, and reducing costs. Moreover, it highlighted the importance of accurate modelling, input data validation, and simulation verification and validation for achieving reliable and valid results.

The simulation model was designed using DES software, and the model's input data was validated by collecting data from Alpha's plant. The results of the simulation showed that the new fleet of LGVs significantly improved the overall efficiency of the warehouse by reducing the average cycle time, travel distance, and the number of vehicles required. Moreover, the simulation results showed that the new fleet of vehicles is capable of handling the current and future demands of the warehouse, ensuring smooth and uninterrupted operations.

In conclusion, this study demonstrates that discrete event simulation is a powerful tool for optimizing warehouse operations. By validating a new fleet of LGVs, this study provides valuable insights into the potential benefits of automation in warehouses. The results of this study can help warehouse managers and logistics professionals in the food and beverage industry to make informed decisions about implementing automation systems and optimizing their operations.

Despite the interesting implications, some limitations can be highlighted. Firstly, the study only focused on one warehouse, and the results may not be extendable to other warehouses or industries. Secondly, the study assumed that the simulation model inputs were accurate and representative of real-world conditions. Thus, future research could focus on improving the accuracy of the input data (Kmiecik, 2022), the input of this model was mainly deterministic and equally split in time. In this study, the number of forklifts currently handling the flows in the warehouse and the key performance indicators were not considered because not available. On one hand, having this data would have been valuable to provide a fair comparison of the two systems. On the other hand, it is worth noticing that the two systems are radically different, and one might argue that some comparisons would be pointless. On top of that, the study did not consider the impact of external factors, such as weather conditions or supply chain disruptions, on warehouse operations. Thus, future research could focus on developing simulation models that incorporate these external factors to provide more realistic and accurate results. Moreover, the research focuses on measuring performance related to warehouse automation but excludes other implications such as economic, environmental, and social factors. Therefore, future research could consider the benefits and challenges of automation considering these aspects within the relevant and innovative framework of the Warehousing 5.0 paradigm.

Overall, this study provides a valuable contribution to the literature on warehouse automation and validation using DES, and it highlights the potential benefits of automation for the food and beverage industry. The results of this study can be used to inform future research and provide insights to warehouse managers and logistics professionals seeking to optimize their warehouse operations.

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