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Employing Simulation Models for Addressing Issues in Warehouse Systems

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Abstract

Aim: The aim of this article was to investigate whether the appropriate arrangement of products on warehouse shelves significantly affects order fulfillment time, and whether the use of computer simulation can be helpful in warehouse management.

Methodology: A series of simulation studies was conducted using FlexSim software, version 22.2.2. The simulation involved examining which of the three selected variants of product arrangement in the warehouse was most advantageous. Each case was analysed in terms of such parameters as: order fulfillment time, revenue, number of undelivered pallets, and financial outcome.

Results: The conducted simulation studies allowed for the selection of the optimal strategy for product placement in the warehouse.

Implications and recommendations: In view the conducted research, it can be concluded that changing the method of arranging goods on warehouse shelves can significantly improve the efficiency and effectiveness of warehouse processes. Furthermore, the results of the analysis of warehouse processes using simulation confirmed that it is an effective decision support tool for optimising warehouse processes.

Keywords: warehouse management, product storage, product placement, simulation models, discrete event simulation

1. Introduction

Computer simulation, applied for over thirty years in the field of manufacturing, remains a valuable tool in various areas of business and industry (Kłosowski, 2011), and indicated by Nowak (2007), in the exact sciences and engineering. Thanks to the use of simulation, it is possible to accurately replicate processes occurring in real systems and conduct multi-variant analysis to find the best solution. The first part of the paper provides a brief literature review on the use of computer simulation in various branches of industry. Examples of computer simulation applications and the benefits derived from their practical use are also presented. The next section shows the results of a simulation conducted to optimise the operation of a grocery product warehouse by changing the layout of products on the shelves. Finally, the conclusions and recommendations are provided.

This paper aimed to identify the most effective arrangement of products on shelves that minimises the time needed to complete orders by employees of a grocery warehouse, as well as to investigate whether computer simulation, specifically FlexSim software, can be helpful in warehouse management.

The research problem was formulated in the form of the question: “Is it possible to optimise the efficiency of warehouse space through appropriate allocation of products in available storage areas?” Formulated in this way, the research problem has led to the following research hypothesis:

H1: The appropriate arrangement of products on warehouse shelves significantly affects the time required to complete orders.

The research gap concerned assessing the potential of computer simulation in warehouse logistics regarding the optimal arrangement of products on the shelves, lacking the practical validation of the feasibility of utilising this technology in real operational conditions.

The analysis of the available literature on simulation indicated that these tools are indeed widely used in different areas (Greasley, 2003). They are utilised by warehouse and distribution centre managers who must address numerous issues related to managing the designated areas, the method of product storage, as well as their allocation. Gagliardi et al. (2007) analysed whether specific strategies for sharing warehouse space can lead to a reduction in operational costs while maintaining a high level of service. To achieve this, they developed a simulation model of logistic operations in a real warehouse with high throughput which handles over 12 million references annually. Preliminary results show that potential savings can be achieved by reducing inventory levels in the picking area, where customer orders are collected. Similar analyses were conducted by Renaud and Ruiz (2008).

Isa Aliyu et al. (2015) emphasised that in a warehouse, all processes occurring in the loading and unloading zones are initiated simultaneously. In their work, the authors presented and discussed simulation models built in ARENA software for loading and unloading systems in the warehouse. The aim of the study was to find a strategy that would optimise the time each truck spends in the warehouse. The analysed processes in the unloading zone included checking, unloading, stacking, sealing, and storing products, while in the loading zone, order processing, picking, sealing, loading, and checking the load directly on the truck were also examined. The developed model served for the analysis of employee utilisation and the identification of bottlenecks in the system. It was identified that the time between customer truck arrivals, waiting time for order picking, sealing, and loading processes, as well as the number of forklift trucks, were the factors influencing system efficiency. The unloading process using a company truck did not constitute a bottleneck. The authors developed and compared four improvement models. It was found that with relatively the same other factors, by adding a forklift and a driver, the selected model not only eliminated overtime issues but also reduced customer waiting time by almost two hours, i.e. by over 65%. Similar analyses and developments were presented by Greasley (2003), Deshpande et al. (2007), and Tahar and Hussain (2000).

Tan et al. (2010) proposed several concepts of sustainable simulation models for enterprises. Social, environmental, and economic models were developed and implemented using iThink software for a warehousing and distribution company. The article utilised the system dynamics paradigm to model sustainable enterprises and the iThink system for implementing the created models. The authors also discussed the interrelations between different dimensions of sustainable development to develop the models. The importance and usefulness of sustainable development models in everyday decision-making were confirmed by the management of the analysed distribution company. The proposed concepts, which were examined, developed, and verified, are applicable to most enterprises operating in the logistics industry.

Amorim-Lopes et al. (2021) presented a three-stage methodology that applied probabilistic simulation, optimisation, and event-driven simulation (SOS) to analyse and experiment with the layout and storage policy of goods to improve picking efficiency. In the first stage, picking efficiency is estimated based on various principles of allocating goods in the warehouse and zone configurations using a probabilistic model. In the second stage, a mixed-integer optimisation model defined the overall layout of the warehouse by selecting configurations and storage policies for each zone. Finally, the optimised layout solution was tested under uncertain demand conditions in the third and last stage of simulation using a discrete event simulation model. The SOS methodology was validated using three months of operational data from a large retail distributor warehouse, successfully demonstrating how it can be effectively used to improve distribution warehouse efficiency.

Due to the limited scope of this paper, the authors omitted a literature review in favour of presenting the results of the conducted simulation studies and achieving the goal of this work.

2. Materials and Methods

The subject of the research was a computer-generated warehouse space functioning as a wholesaler of grocery products. It offers its customers a diverse range of products, ranging from groceries to small household electronics and chemicals. The warehouse space has a section dedicated to refrigeration where grocery products requiring special storage are stored. The warehouse's customers are grocery and chemical product stores from nearby cities.

A series of simulation studies were conducted using FlexSim software version 22.2.2 The simulation aimed to determine the most favourable product layout in the warehouse. For this purpose, three scenarios were prepared, each with a different product arrangement in the warehouse. In the first scenario (Scenario 1), the arrangement was random; the second (Scenario 2) followed the Pareto principle, with products placed individually on each shelf, and in the third scenario (Scenario 3), the Pareto principle was also applied. In contrast to earlier scenarios, where only one type of product could be stored on each shelf, in this case two types of products could be accommodated on one shelf, allowing for better use of warehouse space. Thus, the Pareto principle referred to the observed demand for warehouse resources. The products were arranged in order of decreasing demand, and based on this, allocation to specific shelves was made.

The following assumptions were formulated:

- A specific number of workers was assigned to each simulation, with no more than 6 workers per workstation.
- Approximately 45 orders were fulfilled daily, with each order consisting of an average of 5 products.
- The number of customers was constant and amounted to 5.
- The available fleet consisted of 5 refrigerated trucks and 10 trucks without refrigeration capability for transporting products.
- The simulation lasted for 5 working days in a three-shift system.

Each simulation was repeated five times with different random seeds to minimise random error. The conducted simulation experiments allowed for the analysis and comparison of the results for each of the adopted scenarios using the appropriate statistical tools (mean, standard deviation).

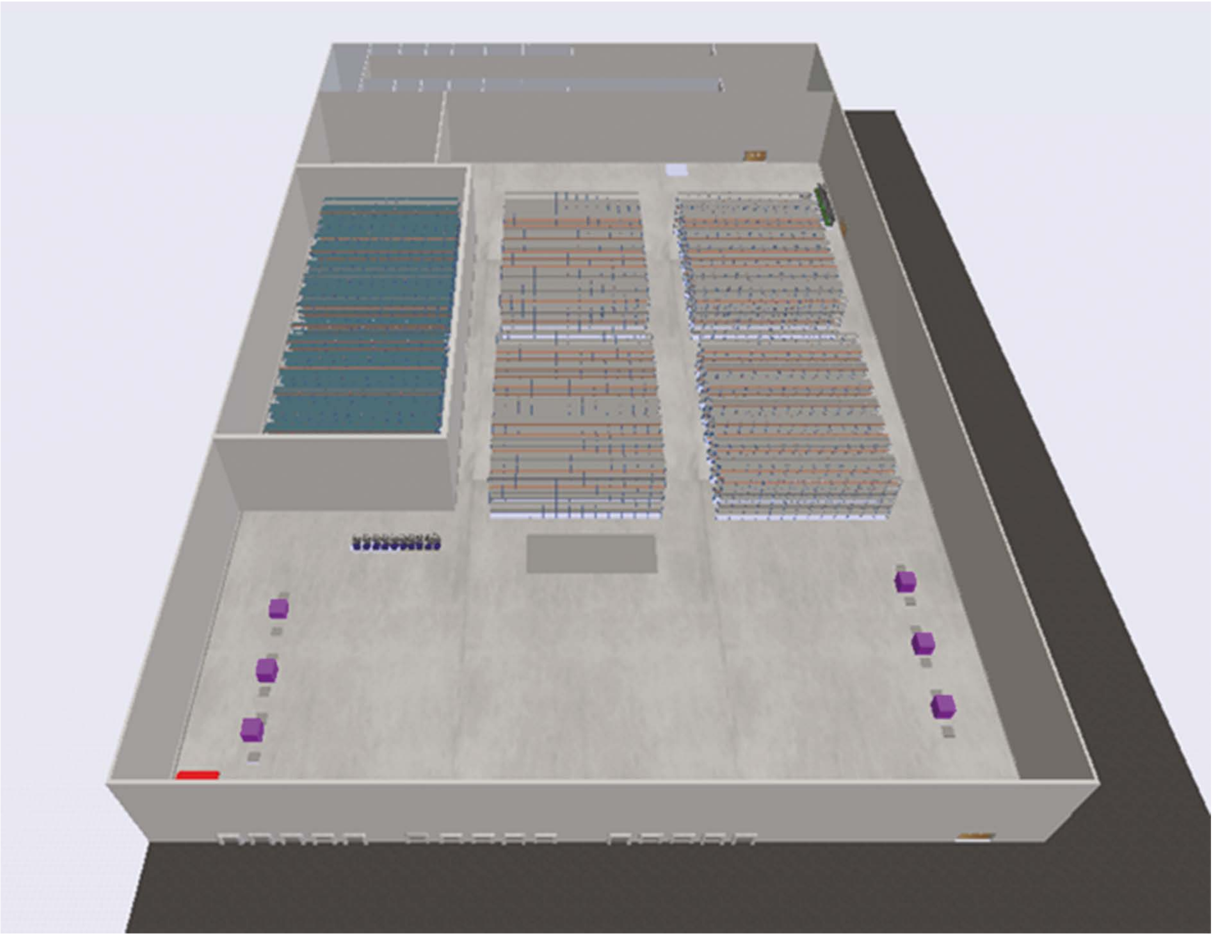

Figure 1. Simulation Model View in FlexSim
Rysunek 1. Widok modelu symulacyjnego FlexSim

Source: own work / Źródło: opracowanie własne.

The simulation model consisted of a warehouse area which has a designated part for refrigeration where products requiring cooling are stored. In this area, order picking for delivery to customers takes place, whilst in the second area, final order preparation and shipping occur. The warehouse model in the FlexSim software is illustrated in Figure 1.

3. Analysis of the Results

To obtain the most efficient arrangement of products on the warehouse shelves, the results of the conducted simulation experiments were analysed. Table 1 presents the order fulfillment times obtained in each of the conducted iterations for each of the defined scenarios.

In the case of Scenario 1, the order fulfillment time ranged from 5.76 min to 6.28 min. For Scenario 2, this time was shortened and ranged from 5.57 min to 6.07 min, whereas in Scenario 3, the order fulfillment time was the shortest, from 5.43 min to 5.85 min.

Table 1. Picking times (in minutes)
Tabela 1. Czasy kompletacji (in minutes)

	Iteration #1 Iteracja #1	Iteration #2 Iteracja #2	Iteration #3 Iteracja #3	Iteration #4 Iteracja #4	Iteration #5 Iteracja #5	Mean Średnia	Sample Std Dev Odchyl. Stand.
Scenario 1	376.80	376.20	363.00	345.60	373.20	366.96	13.16
Scenario 2	364.20	361.80	349.20	334.20	345.60	351.00	12.30
Scenario 3	349.80	349.20	339.00	325.80	351.00	342.96	10.73

Source: own work / Źródło: opracowanie własne.

Similarly, the obtained revenue was analysed. The results are presented in Table 2.

Table 2. Revenue generated (in PLN)
Tabela 2. Uzyskane dochody (w PLN)

	Iteration #1 Iteracja #1	Iteration #2 Iteracja #2	Iteration #3 Iteracja #3	Iteration #4 Iteracja #4	Iteration #5 Iteracja #5	Mean Średnia	Sample Std Dev Odchyl. Stand.
Scenario 1	23740.00	24416.00	27385.00	28123.00	29215.00	26575.80	2383.30
Scenario 2	19361.00	24626.00	25352.00	29453.00	30129.00	25784.20	4333.68
Scenario 3	14804.00	20474.00	25413.00	27660.00	31772. 00	24024.60	6572.52

Source: own work / Źródło: opracowanie własne.

In Scenario 1, the achieved revenue ranged from 23,740 PLN to 29,215 PLN; in Scenario 2, the results showed greater variability, from 19,361 PLN to 30,129 PLN. Meanwhile, in Scenario 3, the obtained values fluctuated between 14,804 PLN and 31,772 PLN.

The obtained values suggest that the selection of the best solution (scenario) cannot rely solely on the revenue parameter.

Another parameter analysed was the number of undelivered pallets. Table 3 presents the results regarding this indicator for each of the individual scenarios.

Table 3. Number of undelivered pallets (in units)
Tabela 3. Liczba niedostarczonych palet (w szt.)

	Iteration #1 Iteracja #1	Iteration #2 Iteracja #2	Iteration #3 Iteracja #3	Iteration #4 Iteracja #4	Iteration #5 Iteracja #5	Mean Średnia	Sample Std Dev Odchyl. Stand.
Scenario 1	291	286	304	323	293	299.40	14.74
Scenario 2	297	293	313	328	209	288.00	46.29
Scenario 3	311	306	148	338	217	264.00	79.24

Source: own work / Źródło: opracowanie własne.

In the first of the analysed cases, the number of undelivered pallets varied from 286 to 323. In Scenario 2, the values ranged from 209 to 328 units, while in the third scenario, which exhibited the greatest variability in data, these results were between 148 and 338 units.

As the final parameter, the financial results obtained were analysed (Table 4).

Table 4. Financial results (in PLN)
Tabela 4. Wyniki finansowe (w PLN)

	Iteration #1 Iteracja #1	Iteration #2 Iteracja #2	Iteration #3 Iteracja #3	Iteration #4 Iteracja #4	Iteration #5 Iteracja #5	Mean Średnia	Sample Std Dev Odchyl. Stand.
Scenario 1	15236.00	12092.00	10025.00	9657.00	7516.00	10905.20	2914.78
Scenario 2	14610.00	11371.00	8815.00	7822.00	6964.00	9916.40	3100.89
Scenario 3	17767.00	15258.00	14399.00	9689.00	6236.00	12669.80	4635.44

Source: own work / Źródło: opracowanie własne.

In the third scenario, the highest financial result was achieved, amounting to nearly 18,000 PLN. However, it was observed that in this case that there was the greatest variability in the results between successive replications, indicating that the results were more dispersed than in the other scenarios.

4. Discussion

The analysis of Scenario 3, applying the Pareto principle for product arrangement on shelves, demonstrated its effectiveness in optimising warehouse processes. This approach led to a reduction in undelivered pallets, shorter order fulfillment times, and increased financial outcomes. However, the observed variability between replications poses challenges for warehouse managers, as noted in previous studies (Gudzbeler et al., 2018).

Furthermore, the study demonstrated the utility of simulation software, specifically FlexSim, as an effective tool for addressing complex warehouse management challenges. This finding is consistent with the research conducted by Kłodawski (2017), emphasizing the intuitive nature and effectiveness of FlexSim in ensuring worker safety.

The broader implications of this research contribute to the understanding of warehouse management practices. By optimising processes through simulation and implementing strategies such as the Pareto principle, warehouses can strive for greater efficiency and operational effectiveness, as indicated by prior studies on crane handling (Kalwasiński, 2019), warehouse operating strategies (Chodak, 2004), and logistic process reengineering (Mendlikowski & Pawlewski, 2015).

5. Conclusions

In conclusion, the findings of this study support the implementation of the Pareto principle for product arrangement in warehouses, particularly in Scenario 3, as it offers substantial benefits in terms of efficiency and effectiveness. Despite challenges related to variability, the use of simulation software such as FlexSim proved invaluable for optimising warehouse processes, in line with previous research findings. This highlights the importance of leveraging simulation tools and strategic approaches to enhance warehouse operations and improve overall performance.

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Wykorzystanie modeli symulacyjnych do rozwiązywania problemów w układach magazynowych

Streszczenie

Cel: Celem niniejszego artykułu jest próba uzyskania odpowiedzi na pytanie, czy odpowiednie ułożenie produktów na regałach magazynowych wpływa w znacznym stopniu na czas kompletacji zamówień oraz czy wykorzystanie symulacji komputerowej może być pomocne w zarządzaniu magazynem.

Metodyka: Przeprowadzono szereg badań symulacyjnych zrealizowanych przy wykorzystaniu oprogramowania FlexSim. Symulacja polegała na sprawdzeniu, które z trzech wybranych wariantów ułożenia produktów na magazynie jest najkorzystniejsze. Każdy przypadek przeanalizowano pod względem parametrów, takich jak czas kompletacji zamówień, dochody, liczba niedostarczonych palet oraz wynik finansowy.

Wyniki: Przeprowadzone badania symulacyjne pozwoliły wybrać najlepszą strategię rozmieszczenia produktów w magazynie.

Implikacje i rekomendacje: W świetle przeprowadzonych badań można stwierdzić, że zmiana sposobu ułożenia dóbr na regałach magazynowych może znacząco poprawić wydajność i efektywność procesów magazynowych. Ponadto wyniki analizy procesów magazynowych za pomocą symulacji potwierdziły, że jest to skuteczne narzędzie wspomagające podejmowanie decyzji dotyczących optymalizacji procesów magazynowych.

Słowa kluczowe: gospodarka magazynowa, składowanie produktów, rozmieszczenie produktów, modele symulacyjne, symulacja zdarzeń dyskretnych