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VIRTUAL SIMULATION MODELING AS A KEY ELEMENT OF WAREHOUSE LOCATION OPTIMIZATION STRATEGY

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Abstract:
This article examines the utilization of computer simulation techniques for optimizing warehouse locations, an essential component of efficient supply chain management. The study employs a detailed simulation model built using FlexSim software to analyze various decision-making scenarios and identify the optimal warehouse locations while considering market demand for different products. The model integrates a finite set of decision variables and constraints specific to the logistics problem, offering a structured approach to evaluate alternative strategies. Key stages in the development of the simulation model are outlined, including the definition of input parameters, the execution of simulations, and the interpretation of results. The findings demonstrate that virtual simulation modeling significantly enhances decision-making processes by providing precise insights into the interactions within the distribution network. Additionally, the use of simulation results in considerable time and cost savings by reducing the need for costly physical trials. This research underscores the effectiveness of computer simulation in optimizing warehouse locations, contributing to improved supply chain performance and operational efficiency.

Key words: *warehouse location optimization, computer simulation, FlexSim, logistics*

INTRODUCTION

In today's dynamic market and with the increasing expectations of customers, effective supply chain management becomes a key success factor for businesses [1]. One of the key elements of this management is the optimization of warehouse locations, which serve as distribution centers where storage, picking, and distribution of goods take place [2].

Virtual simulation modeling, as a branch of operational analysis, is becoming an increasingly popular tool in the process of optimizing warehouse locations [3]. Computer simulation allows for the creation of virtual models of real logistic processes, enabling the testing of different scenarios and strategies without the need to involve costly physical resources [4].

Here are numerous current literature sources that emphasize the importance and effectiveness of using virtual simulation modeling in warehouse location optimization [5, 6, 7]. According to research conducted by Beaverstock et al. [4], computer simulation allows for a better understanding of the complex interactions occurring in the distribution process, leading to more precise location decisions. Furthermore, studies have shown that the use of computer simulation can result in significant time and cost savings by eliminating the need for costly experiments on real systems [8, 9, 10, 11, 12].

In this article, we analyze the application of virtual simulation modeling in the process of warehouse location optimization. We will present the latest trends, methods, and best practices in this area, based on current scientific research and practical applications in the industry.

ISSUES REGARDING OPTIMAL WAREHOUSE LOCATION

The issue of optimal warehouse location is a common challenge in logistics, which can be considered in a broader context of applications in various fields. Warehouse location can concern not only distribution centers but also wholesalers, storage locations, or even the arrangement of machinery within a manufacturing facility [13]. In the field of operations research, there are many methods for solving this problem, one of the simplest being the centroid method [14].

The centroid method allows for the quick determination of the location of a single object. It is based on two types of metrics: rectangular and Euclidean. Using the rectangular distance, also known as the Manhattan, taxi-cab, or city metric, we calculate the distance between two points by summing the absolute differences of their coordinates [14, 15].

On the other hand, to calculate the typical Euclidean distance, we use an appropriate mathematical formula. More information about the centroid method can be found in extensive literature on operations research. Furthermore, practical applications of this method are widely described in the literature, such as in the work by Kuczyńska and Ziółkowski [16].
In cases where it is necessary to determine the location of a larger number of warehouses or to consider more complex conditions, such as different vehicles, capacities, various costs on individual segments, or rapidly changing order quantities, it is recommended to use more advanced methods such as simulation models, which can be more effective in such cases [17].
In simulation optimization, there are many approaches, but evolutionary approaches are most commonly used. These approaches involve exploring various possible solutions based on a set of existing solutions. Examples include methods such as scatter search or genetic algorithms. Through them, we can explore large solution spaces, performing fewer simulation tests[18, 19].
The simulation optimization process typically works iteratively. The simulation model generates results based on a set of input data. The optimizer uses various rules to change these input data to improve the results. Although these rules (heuristics) are fast, they do not guarantee the best results but can lead to better solutions [20].
For warehouse location, tools such as FlexSim are important for simulating different scenarios. FlexSim allows for creating complex models to investigate how various factors affect warehouse operations [21].
Simulation modeling in FlexSim can be optimized using OptQuest software. OptQuest is a product of OptTek Solutions, which is integrated with FlexSim [22]. It uses evolutionary algorithms to search the solution space for the best results. This process involves repeatedly running the simulation model and modifying parameters based on the results until the best solution is found [23].
Optimization continues until certain criteria are met, such as analyzing all possible solutions or the expiration of a set time. After the process is completed, the best-found solutions are reported. However, technically speaking, there is a risk that they may not always be optimal.

RESEARCH PROBLEM

In this article, the following research problem has been considered: A network of furniture stores (FS) delivers furniture to its retail outlets scattered throughout the country. At the same time, the network receives orders from customers for furniture delivery for the next month. The task is to determine the location of the distribution center (DC) from among the provided locations marked by red dots on the map (Fig. 1) and to specify which store should receive deliveries of a particular type of furniture to minimize the transportation costs of goods while simultaneously meeting the market demand for furniture in the upcoming month.

The locations of the retail stores (FS1, FS2, FS3, FS4, FS5, FS6) are distributed across different regions of the country, marked by blue dots on the map (Fig. 1).
The average monthly quantities of transported furniture to the stores are as follows:

- FS1: 5 units
- FS2: 7 units
- FS3: 12 units
- FS4: 3 units
- FS5: 7 units
- FS6: 4 units.

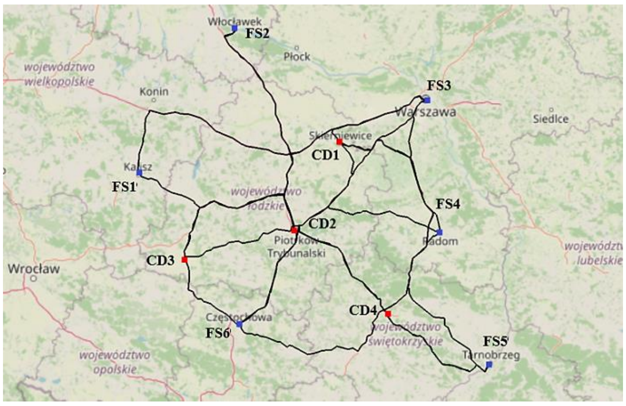


Fig. 1 Location of stores – blue dots and potential distribution centers – red dots

Stores can change their furniture assortment once a month at no additional cost. The company has one vehicle, which can transport one type of furniture at a time, marked in the model as a specific type of box. The unit transportation costs are the same for all retail stores and depend on the number of kilometers traveled.
The choice of the distribution center (DC) location aims to minimize the overall cost of transporting furniture to all retail stores while simultaneously considering the market demand for individual types of furniture. Meanwhile, assigning each store the appropriate type of furniture aims to optimize the delivery route and meet market demand.
To solve this problem, the 3D FlexSim simulation environment with the built-in optimization module OptQuest [22] was utilized. Fig. 2 illustrates the model for the analyzed problem.

Fig. 2 Simulation model for the discussed problem built in the FlexSim environment

In this model, the source is an object generating the assortment of ordered goods and simultaneously serves as a storage location for information about the optimal choice of the distribution center location. This information is stored at the definition point of the output port from the source. Additionally, the model defines 4 queues symbolizing distribution centers marked as (DC) and 6 queues (FS) symbolizing individual furniture stores. Other objects used in the model include maps and points. Maps are used to represent geographic information in the form of latitude and longitude coordinates, while points are used to define locations in geographic coordinates. When combined, they create routes that task performers can traverse between points using the GIS Navigator [24]. The *TaskExecuter* object was selected as the means of transportation.

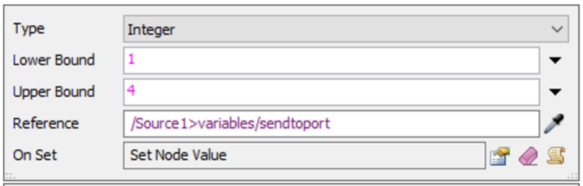
In the model, the following connections are defined:

- The source is connected to 4 distribution centers (DC), where the output port sequence determines the choice of a particular distribution center.
- Each distribution center (DC) is connected to each furniture store (FS), where the port sequence determines the type of products delivered.
- The task performer is connected to each distribution center (DC) via central ports.
- The distribution centers (DC) are connected to the corresponding locations on the map marked by red points, while individual furniture stores (FS) are connected to the corresponding locations on the map marked by blue points.

The defined model is ready for execution, and various scenarios can be considered to calculate the shortest route. For example, as the first solution, we can choose distribution center (DC1) and begin analyzing the order of delivering goods to the 6 furniture stores (FS). Therefore, we need to consider 6! = 720 combinations. With four distribution centers, this amounts to 2880 possibilities. Manual checking of so many scenarios would be inefficient. To address this, it's worth utilizing the *OptQuest* optimizer.

In this task, the optimizer requires 2 input parameters. One parameter concerns the output port numbers of the source, to which each distribution center is assigned (Fig. 3a). This is one of the variables that will be used in the optimization process and also the place where the optimizer will generate results from subsequent iterations.

a)



b)

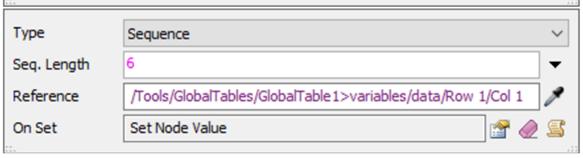


Fig. 3 Definition of input variables:
a) Parameter 1 concerns the port number to which each distribution center is assigned,
b) Parameter 2 – sequence of port numbers for each distribution center

To define this parameter, it needs to be added from the *Toolbox* library. Then, in the Value column, select *Integer* as the variable type and set the range from 1 to 4. Subsequently, using the probe, indicate *Source > Properties > SendToPort*.

The second parameter concerns the sequence of port numbers for each distribution center, which in turn depends on the type of item (Fig. 3b). To define this, add a *GlobalTable* with dimensions 6x1, where the row number represents the item type and the column number represents the port to which the queue symbolizing the respective furniture store (FS) is connected.

The length of the sequence should be set according to the number of output ports for (DC), which is 6 (Fig. 3b).

To ensure that the distribution centers (DC) know they need to use the calculated sequence of port numbers to address the appropriate goods, in the *Output* tab in the *Send to Port* window, select *Port By Case* and indicate the combination of port numbers established in Variable Parameter 2 (Fig. 4).

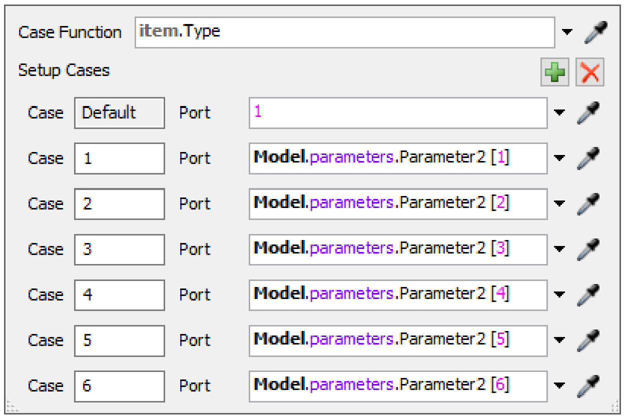


Fig. 4 Port addressing for DC depending on the type of item

The output variable (objective function) will be the total distance read from the *TaskExecuter* object. This parameter needs to be defined by adding it from the *Toolbox* library as a *Performance Measure* variable. Assign this variable to the objective function as *Total Distance Travel* (Fig. 5).

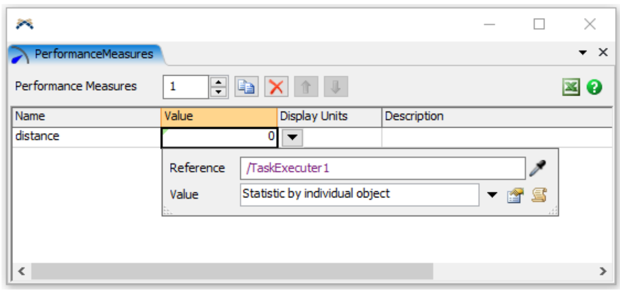


Fig. 5 Definition of the objective function – output variable for the total distance from the TaskExecuter object

In the optimizer settings, 40 feasible solutions have been considered. The optimization direction has been set to minimize the transportation distance. The remaining optimizer settings are shown in Fig. 6.

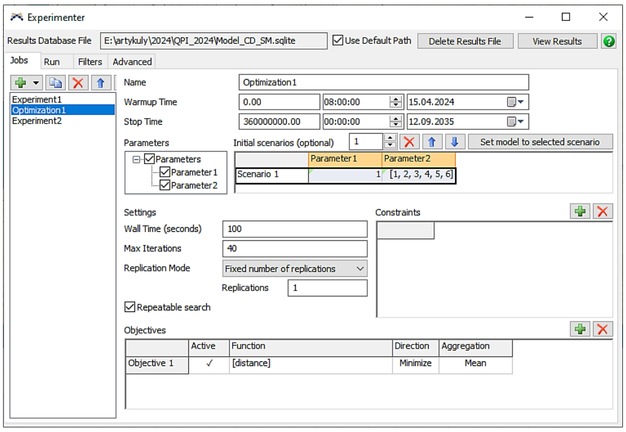


Fig. 6 FlexSim optimizer configuration

ANALYSIS OF THE RESULTS

As a result of the optimizer's work, the optimal combination of ports has been obtained, ensuring the shortest route. Fig. 7 shows the results of the optimizer's work for 40 iterations along with the distances traveled during the route.

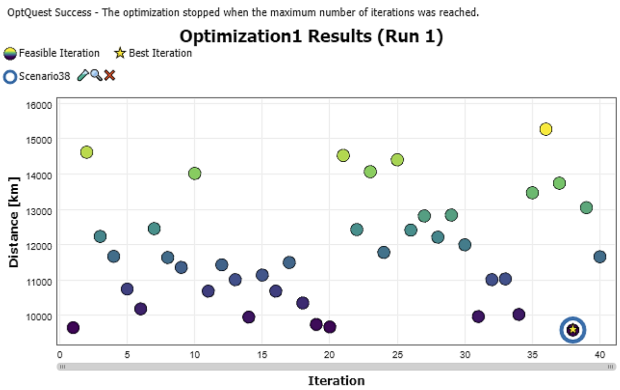


Fig. 7 The result of the optimizer's work

It turned out that the best port addressing sequence is to choose distribution center CD2, followed by selecting output ports numbered 1, 4, 6, 5, 3, 2. This result was achieved after 38 iterations. This means that furniture of the first type in the quantity of 5 units should be delivered to store FS1, furniture of the second type in the quantity of 7 units to store FS4, furniture of the third type to store FS6, furniture 4 – FS5, furniture 5 – FS3, and furniture 6 – FS2. As a result, the total length of the vehicle's route will be the shortest and will amount to 9580.21 km.

On Fig. 8, the front of solutions obtained for different distribution center (DC) locations is depicted, which have been labeled on the ordinate axis as Parameter1.

The front of solutions is a graphical representation of solution efficiency in a multi-objective optimization problem, where each solution is evaluated based on several criteria simultaneously. It is noticeable that the best results, i.e., optimal or close-to-optimal solutions, are achieved for the distribution center location CD2.

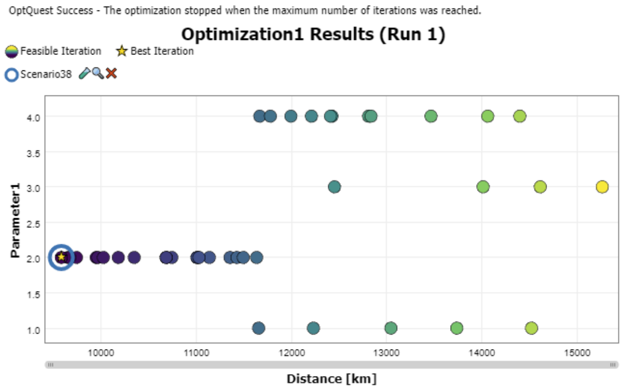


Fig. 8 Front of solutions obtained for different distribution center (DC) locations – Parameter1

This location achieves the highest evaluation parameter values, suggesting that it is the most favorable in terms of meeting all optimization criteria. It is clear that other distribution center locations (CD1, CD3, CD4) yield poorer results, confirming that choosing CD2 is the best solution in the context of the considered optimization criteria.

In Fig. 9, there is a flowchart of order fulfillment, presenting the process of delivering goods to individual stores.

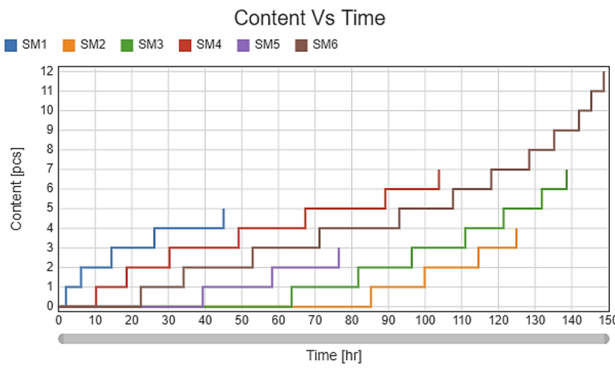


Fig. 9 Flowchart of order fulfillment

Analysis of this flowchart reveals a relatively low level of balance in order fulfillment, indicating that delivered goods to different stores are fulfilled at varying times. There is noticeable variability in delivery times, partly resulting from quantitative differences in orders to individual stores. In some cases, stores receive larger quantities of goods, which may lead to faster fulfillment, while other stores may receive smaller quantities, causing delays in deliveries. It is important to understand these variations and take action to increase balance in the order fulfillment process, contributing to more efficient delivery logistics.

CONCLUSION

The study examined the optimization problem of warehouse location in the context of efficient supply chain management. Using computer simulation in FlexSim and the OptQuest optimizer, the authors experimented with various warehouse location scenarios and distribution strategies.

By defining a simulation model in FlexSim and parameterizing the optimizer, researchers analyzed various possibilities for distribution center locations and delivery routes to retail stores. The experiment focused on minimizing transportation costs while simultaneously considering market demand for different types of furniture.

The results of the experiment indicated an optimal combination of distribution center locations and delivery routes, minimizing the total route length and transportation costs. The best results were obtained for specific distribution center locations, confirming the effectiveness of the applied optimization method.

The analysis of the results also revealed some inequalities in the process of delivering goods to stores, suggesting the need for further actions to increase balance in distribution and achieve more efficient supply chain management.

In summary, the experiment demonstrated the effectiveness of using computer simulation and optimization in the warehouse location optimization process, which can contribute to better supply chain management and cost savings for businesses.

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