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WAREHOUSE LOCATION PROBLEM IN SUPPLY CHAIN DESIGNING: A SIMULATION ANALYSIS

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Abstract:

The facility location problem is a popular issue in the literature. The current development of world economies and globalization of the market requires continuous improvement of methods and research in this field. The location of the object determines the time of transport, affects the operational costs of the supply chain, and determines the possible amount of inventory or minimum inventory levels. These are critical issues from the point of view of designing an effective logistics system. The degree of complexity of current decision-making problems requires the construction of mathematical models and support for the decision-maker by optimization and simulation methods. A comprehensive and systemic approach to the problem allows the effective planning of supply chains.
The purpose of this article was to study the sensitivity of the warehouse location problem in the supply chain. The solution was obtained based on the methodology developed under the SIMMAG3D project. The article presents the characteristics of the issue of the location of warehouse objects, the mathematical formulation of the solved problem of location and the method of its solution based on the heuristic algorithm using the modification of the Busacker-Gowen method. Then, a supply chain simulation model was developed in the FLEXSIM environment and scenario studies were performed for various input data and model parameters. The analysis and assessment of the solution based on parameters such as utilization of the potential of warehouse objects object were presented. Random change in demand described by Erlang distribution and normal distribution was considered. The analysis showed how the selection of a statistical distribution to describe the input data can affect the shape of the logistics system. The article ends with a summary of considerations and a plan for further research in the use of the simulation environment to support the decision-making process of the location of storage facilities and the functioning of supply chains.

Keywords: *facilities location, solution sensitivity testing, simulation model, FLEXSIM, SIMMAG3D.*

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1. Introduction

Designing of the logistics system, regardless of the industry, is a complicated task. Incorrect decisions in this matter result in the ineffective implementation of transport and storage processes. Thus it may lead to loss of competitiveness on the market and also other serious consequences, including the bankruptcy of an enterprise or group of enterprises.

The form, number of elements, connections, and means of transport, or organization should be adapted to the needs arising from the specifics of a given enterprise or group of enterprises. Currently, it is popular to create supply chains and even logistic networks cooperating at a high level of integration, exchanging sensitive data with each other, and sharing the risk of investment decisions.

The functioning of the system is primarily dependent on its proper shape in both organizational and structural terms. As the structure of the system and related investments in new facilities, new production plants, or decommissioning of existing ones are expensive and subject to high risk, proper analysis of the effects of such decisions is necessary. Decision support in this area is possible by using appropriate methodology and optimization or simulation tools. This work uses the methodology developed as a result of the SIMMAG3D project. The project was implemented at the Faculty of Transport of the Warsaw University of Technology, and one of its elements was the use of mathematical modeling and heuristic algorithm to determine the location of storage facilities (Jacyna et al., 2017).

The purpose of this article is to present the possibilities of using the FLEXSIM simulation environment in the study of the location issue in the context of assessing the system's sensitivity to changes in notification stream parameters. In addition, the analysis of the results obtained will allow conclusions to be drawn regarding the parameterization and selection of the supply chain structure, which is justified by the provision of flexibility and resistance to disturbances in the logistics system (Szczepański et al., 2017).

The research conducted in this article includes:

- characteristics of the issues of warehouse facilities location in the logistics system,
- developing a simulation model and its parameterization in the FLEXSIM environment,
- scenario studies of process implementation in the developed distribution system,
- analysis of the results obtained in terms of system sensitivity to changes in statistical distributions describing streams and the service process,
- conclusions from the conducted research, recommendations and a plan for further research.

2. Description of warehouse facilities location problem in the logistics system

The location problem has been presented in the literature for a long time. It is a widespread decision-making issue in the context of both business operations and academic considerations. The primary object location model, which is the starting point for more advanced and sophisticated problems, is the discrete model in which one object is selected from a set of potential locations. The selection of this location is based on minimizing the total cost, distance or time. This problem is often referred to as p-median, and many works can be found in this aspect, e.g. (Daskin, 1995; Drezner and Hamacher, 2004; Mirchandani and Francis, 1990; Revelle and Eisel, 2005). Developments and modifications of this issue are made for the real conditions of the location and ensuring a better quality solution to the problem.

The basic model, the simplest to use, has many assumptions that generalize and simplify the issue, and thus affect the quality of the solution. Such assumptions are usually the location of a single object, and planning takes place based on a single period, a homogeneous assortment, demand, flows, costs are determined. The above models turn out to be insufficient for practical application, and the solutions obtained from their solution are characterized by high susceptibility to change of input parameters. As a result, many different models are created, including a number of assumptions, depending on the problem nature and the needs of the decision-maker.

In recent years, changes in the markets have resulted in the need to rebuild decision models and forms of providing transport and storage services. It results from the progressing globalization and development of some areas, e.g., e-commerce. This is associated with shortening the life of products, greater dynamics of changes in demand, and uncertainty. Determining the effective configuration of the supply chain to perform functions that meet current and future needs require consideration of many aspects. Based on work e.g. Govindan et al. (2017), Ortiz-Astorquiza et al. (2018), Owen and Daskin, 1998. synthesizing location problems, we can distinguish the main assumptions that are adopted in object location models.

The most critical assumptions in planning the location of logistics facilities take into account the time horizon for which planning is considered, a. strategic, tactical and operational (Bender et al., 2002; Vidal and Goetschalckx, 1997). Depending on the time horizon, other assumptions are taken into account: change of parameters over time, random needs, and location of suppliers, customers. This has an impact on the definition of the needs regarding the configuration of the facilities (including, e.g. the capacity of the warehouse facility) and thus the operating costs. Such decisions can also include the selection of a suitable object profile, e.g., taking into account the specific requirements of the industry or the location in the supply chain (e.g., production warehouse, distribution warehouse). Shaping the entire supply chain requires taking into account the issues of object hierarchy and multi-levelness at the same time (Farahani et al., 2014; Ortiz-Astorquiza et al., 2018; Wasiak et al., 2017). As indicated in the work (Melo et al., 2009), modifications to the basic location problems were limited, however, by methods of solving them. Therefore, despite taking into account, e.g. randomness, critical assumptions necessary for supply chain management are omitted, including, e.g. flow between objects at the same level.

To sum up, distinguishing between models can be reduced to the form of a problem of the location of a single object or multiple objects, deterministic/stochastic model, single-layer / multi-layer, single planning period / longer time horizon, homogeneous / heterogeneous assortment. In addition, the model takes into account the constraints and additional decision problems that include material flow capabilities, inventory management, production issues, and the allocation of resources to tasks. The main criteria for conditioning the choice of the solution are based on the costs and time of task implementation. In the paper Melo et al. (2009) three categories of cost factors were distinguished, taking into account international factors, financial and tax incentives, and investment expenses. Additional criteria result from the preferences of decision-makers and may take into account, e.g., the number of transport means or employees involved, the allocation of resources to tasks, the distance traveled by vehicles or ecological criteria (Afshari et al., 2014; Dukkanci et al., 2019; Jacyna et al., 2018; Jacyna-Gołda et al., 2018).

As already mentioned, on the one hand, the construction of models depends on the needs of decision-makers; on the other hand, the possibility of using methods allowing the solution of formulated tasks. The methods of locating point infrastructure in a transport network can be divided into:

- approximate and accurate - due to the returned solution,
- single and multi-criteria - number of evaluation functions,
- single and multi-echelon - taking into account the hierarchy of points,
- static and dynamic - taking into account the time,
- descriptive, analytical, analytical-descriptive, analog and numeric.

To solve object location problems, the method of distance minimization or the gravitational method is the most common. It takes into account one criterion for location selection and works based on heuristic methods. There are also its modifications consisting of, e.g., taking into account the importance of some areas or individual recipients, as well as introducing delivery costs. However, this method is limited to simple tasks. Another way to pay attention to is the descriptive and analytical method involving the search for organizational variants for which a reduction in inventory maintenance costs offsets the sum of transport and storage costs (Daskin, 1995; Owen and Daskin, 1998).

The methods classified according to the number of criteria are an essential group. Appropriate selection of criteria allows characterizing the decision problem taken unambiguously. The most frequently chosen criterion is the cost of distribution or its implementation time. These tasks involve solving transport or vehicle routing (VRP) tasks. Solving such tasks requires the use of appropriate computer applications that allow for taking into account a lot of restrictions. Multi-criteria location selection methods can be divided into multi-criteria analysis methods and multi-criteria optimization (Farahani et al., 2010; Jacyna-Gołda et al., 2018). Optimization methods in a multi-criteria approach rely on the determination of optimal variants in terms of pareto or weighted criterion functions as well as the transfer of the criterion to constraints. The use of multi-criteria optimization requires from the decision-maker a lot of knowledge to correctly define the needs and define the space of solutions (Farahani et al., 2010; Jacyna-Gołda et al., 2018).

A relatively new approach is the methods of warehouse location based on evolutionary algorithms. They allow solving complex tasks, taking into account, e.g. the passage of time, and thus to include the dynamics of processes or their randomness. Models mapping dynamics allow the use of submodels forecasting service demand. They allow better matching of the capacity of individual facilities as well as periodic fluctuations in demand and supply. It is also possible to take into account the variable duration of individual processes occurring in the facilities as well as the travel times in the transport network. The above methods have been described in detail in the papers (Afshari et al., 2014; Jacyna-Gołda and Izdebski, 2017). The article addresses a single-criterion problem based on the general problem of multi-level location. Many assortments, as well as location characteristics and dimensions of the facility, were taken into account. The formulation of the task is presented in the next section.

3. Formalization of the warehouse facilities location problem and optimization method

In the article, the analysis of the solution of the problem of location taking into account planning for a single period is analyzed, many assortments are moved, many storage facilities between which flows are allowed can be located. This problem is determined, and its solution allows to indicate the location of the object, but also its capacity. The criterion function was reduced to the cost of implementing the daily flow, although the fixed costs of the facility operation were taken into account. This function takes the form of an equation (1), and the restrictions imposed on the solution were written by equations (2-9).

$$\boldsymbol{F(X,Z)} = \sum_{i\in I}\left[\begin{array}{l} x_i \cdot cs_i \cdot fs(v_i) + \\ \sum_{j\in J}\left(\begin{array}{l} \sum_{n\in N} z_{n,i,j}\cdot ct_{n,i,j}\cdot d_{n,i} + \\ \sum_{o\in O} z_{i,o,j}\cdot ct_{i,o,j}\cdot d_{i,o} + \\ \sum_{i'\in I\setminus\{i\}} z_{i,i',j}\cdot ct_{i,i',j}\cdot d_{i,i'} \end{array}\right) + \\ \sum_{j\in J}\left(cw_{i,j}\cdot fw(v_i)\cdot \sum_{i'\in I\setminus\{i\}} z_{i,i',j} + \sum_{o\in O} z_{i,o,j}\right) \end{array}\right] \to \min \quad (1)$$

$$\forall i \in I \qquad x_i \in \{0,1\} \quad (2)$$

$$\forall i \in I \qquad v_i \ge \sum_{j\in J}\left(\sum_{i'\in I\setminus\{i\}} z_{i,i',j} + \sum_{o\in O} z_{i,o,j}\right) \ge 0 \quad (3)$$

$$\forall i \in I \mid x_i = 1 \qquad qt_i \ge v_i \ge qe_i \quad (4)$$

$$\forall i \in I, \forall i' \in I, \forall n \in N, \forall o \in O, \forall j \in J \quad z_{n,i,j} \ge 0,\ z_{i,o,j} \ge 0,\ z_{i,i',j} \ge 0 \quad (5)$$

$$\forall n \in N,\ \forall j \in J \qquad \sum_{i\in I} z_{n,i,j} = s_{n,j} \quad (6)$$

$$\forall o \in O,\ \forall j \in J \qquad \sum_{i\in I} z_{i,o,j} = p_{o,j} \quad (7)$$

$$\forall j \in J \qquad \sum_{n\in N} s_{n,j} = \sum_{o\in O} p_{o,j} \quad (8)$$

$$\forall i \in I \qquad \operatorname{sgn}\left[\sum_{j\in J}\left(\sum_{i'\in I\setminus\{i\}} z_{i,i',j} + \sum_{o\in O} z_{i,o,j}\right)\right] = x_i \quad (9)$$

The criterion function (1) consists of three components. The first concerns the fixed costs of maintaining the facility and it depends on the decision variable x_i defining existence i-th facility in the supply chain and fixed costs for i-th location it is cs_i and a cost-correcting function $fs(v_i)$, which depends on the daily potential of the object, i.e., on the number of transportable load units per day. In the simplest case, the correction function can have a fixed value, e.g., 1, and then the fixed cost per pallet unit will not depend on the size of the object and its potential. The second component is the cost of:

– deliveries to the storage facility resulting from the number of moved units of j-th assortment ($z_{n,i,j}$), unit movement cost ($c_{n,i,j}$) expressed as one unit of distance ($d_{n,i}$);
– deliveries to the recipient resulting from the moved number of units of the j-th set ($z_{i,o,j}$), unit movement cost ($c_{i,o,j}$) expressed as one unit of distance ($d_{i,o}$);
– the moved number of units of the j-th assortment ($z_{i,i',j}$) between storage facilities, unit cost of movement ($c_{i,i',j}$) expressed as one unit of distance ($d_{i,i'}$).

The third component is variable costs resulting from the unit cost of the flow of one j-th assortment unit through i-th facility ($cw_{i,j}$) a function correcting this cost (analogous to the fixed cost) depending on the object's potential $fw(v_i)$ and the sum of flows through i-th facility.

Further elements of the model are restrictions imposed on the solution space. Equation (2) defines the set of values that decision variables can take x_i i.e.

variables of the interpretation of a storage facility existence in *i*-th location. Equation (3) limits the amount of flow through *i*-th facility, on the one hand, it cannot be negative, on the other hand, it cannot exceed the object's potential in *i*-th location. Formula (4) limits the building's potential on the one hand by terrain restrictions qt_i and on the other hand the threshold of profitability qe_i (i.e. the object cannot be too small). Formula (5) ensures no negativity of decision variables that determine the amount of flow in a given relationship. Equations (6) and (7) determine the amount of flow, from supplier to warehouses and from warehouses to recipients, as equal to supply and demand, respectively. In turn, equation (8) indicates equal supply and demand. The last equation (9) states that if there is a flow through *i*-th facility the decision variable that determines its existence must take value 1.

The restrictions and data introduced to allow to eliminate the location of objects with low material flow and at the same time, prefer objects with greater potential by minimizing their overall number. Of course, there is the possibility of modifying the above model by adding periods or adding data on demand and supply. It is also possible to introduce specialization of warehouse objects depending on the accepted assortments, as well as to introduce a hierarchy between objects.

The article is limited to the presented model to show the methodology used to test the sensitivity of the solution. The heuristic method used applies to more extensive optimization models, although it requires some modifications then.

The optimization procedure is based on the Busacker-Gowen algorithm. This method determines the maximum flow with the minimum cost. The Busacker-Gowen algorithm works according to the principle:

1. Find the shortest "empty" path.
2. Send the maximum flow along the selected path.

This method will repeat the above two steps looking for the next path until the maximum flow is reached. The maximum flow is defined as the minimum from the sum of the supply of consignors and the sum of consumer demand. This procedure is also developed in the form of iterative heuristics, i.e., it is iteratively checked for various options for shaping the supply chain by eliminating inefficient and unacceptable solutions. The above-mentioned first stage of the operation of this algorithm can be implemented by any algorithm that finds the shortest path; in this case, the PDM algorithm was used. More detailed information on the Busacker-Goven algorithm and PDM, as well as their applications, can be found, e.g., in Sysło et al. (2006). Approximation methods can be used to solve the problem of localization, especially in the case of complex decision-making issues (e.g. an article Jacyna-Gołda et al., 2018; Jacyna-Gołda and Izdebski, 2017; Wasiak et al., 2017). Sensitivity analysis of these methods using the Flexsim environment will be the theme of other research.

4. Simulation analysis of the location solution in the supply system

4.1. Simulation model - assumptions

Based on the developed model and the data presented below (demand is taken into account - Table 1 and production capacity - Table 2, for 4 types of assortments), the location of warehouse facilities and their estimated capacity were determined. Calculations were carried out on average daily material flows. Thus, the optimization did not take into account random data, but only the need to provide reserve space in the facility for a larger inventory.

The obtained result was implemented in the FLEXSIM. This model is presented in Figure 1. It has been assumed that the entire delivery plan is to take place within 12 hours, while the assortment production time cannot exceed 8 hours. The intensity of production, as well as shipping to the recipient, is determined. Transportation between warehouses is allowed. In turn, direct transport was eliminated, which resulted from the assumptions adopted when determining the solution to the location problem - high transport and storage costs in the case of direct transport.

Table 1. Recipients demand

Recipient \ assortment	Demand (load unit per day)				
	A1	A2	A3	A4	Total
Stare Czarnewo	284	725	180	269	1458
Gromadka	206	336	425	222	1189
Toruń	150	122	161	322	755
total	640	1183	766	813	3402

The location of the two warehouses was obtained as a solution. The warehouse in Poznań has a capacity of 800 load units and the warehouse in Kędzierzyn with a capacity of 600 load units; it is assumed that the minimum time of passage of the unit through the object is two hours.

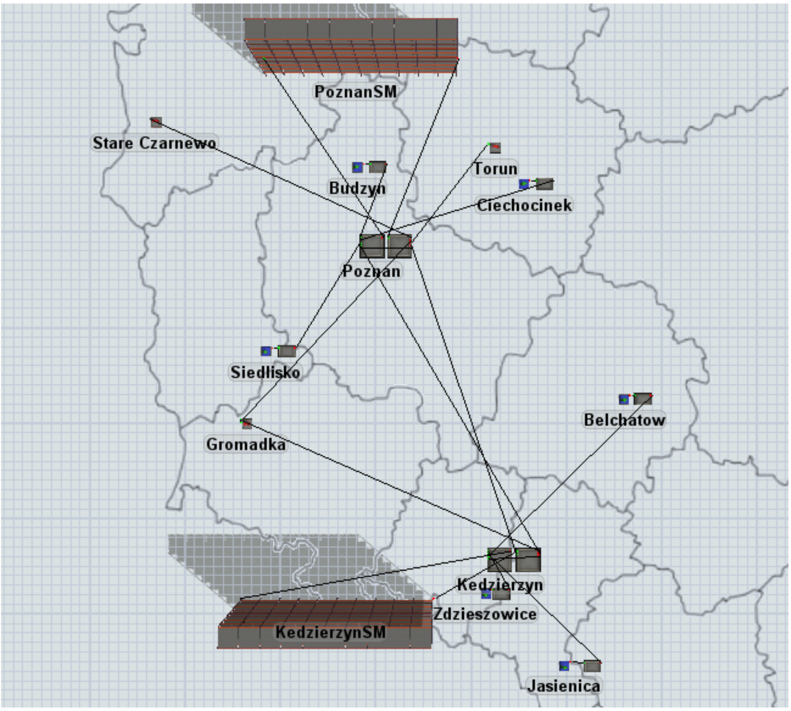

Fig. 1. The simulation model based on the solution of location problem

Table 2. Supplier production capacities

Supplier \ assortment	Supplier production capacities (load unit per day)					supply intensity (s)
	A1	A2	A3	A4	total	
Budzyn	85	133	220	244	682	42
Jasienica	121	276	32	212	641	45
Siedlisko	155	62	239	129	585	49
Zdzieszowi	176	155	269	9	609	47
Belchatów	0	334	0	0	334	86
Ciechocinek	103	223	6	219	551	52
Budzyn	85	133	220	244	682	42

Simulation experiments were carried out for the above solution of the location problem and the mapped simulation model. Seven variants were adopted to assess the sensitivity of the obtained solution. These variants are defined as follows:

– S1 - variant 1 - base option for the data presented above,
– S2 - variant 2 - flows increased by 10%,
– S3 - variant 3 - flows increased by 20%,
– S4 - variant 4 - flows increased by 40%,
– S5 - variant 5 - flows increased by 60%,
– S6 - variant 6 - the demand is described by the Erlang distribution taking into account shape parameters 2, and the scale parameter as 40% of the demand value from the base variant,
– S7 - variant 7 - a normal distribution describes the demand with an average value equal to the value in the base variant, and the deviation assumed as 30% of this value.

In the variants taking into account random demand based on experiments, the necessary level of stock in production was estimated (can be interpreted as a reserve) to ensure an appropriate level of service. It was determined as the sum of the expected value and standard deviation.

4.2. Results of simulation experiments

Simulations were carried out for 7 variants defined. Each variant was 30 replications, which was important primarily for variants 6 and 7 in the form of different random samples for the respective distributions. An example of a graph showing the content of load units in a warehouse facility is shown in Fig. 2. It presents the average and maximum compactness within 12 hours as well as the filling and emptying of the facility over time. The time on the horizontal axis is expressed in seconds, and the vertical axis is the number of load units.

This article focuses on assessing the sensitivity of the solution. This means an assessment of the feasibility of transport operations (transport potential over 12 hours). This is shown in the graphs in Figure 3, where the chart on the left is the demand satisfied, and the graph on the right is the volume of production.

Another feature was the evaluation of the facility's capacity utilization. Figure 4 shows the average and maximum occupancy values for Poznań and Kędzierzyn, respectively. In turn, Figure 5 on the graphs shows the average time at which the facility is full (does not accept additional units) and the sum of time when such an event took place for the warehouses in Poznań and Kędzierzyn, respectively.

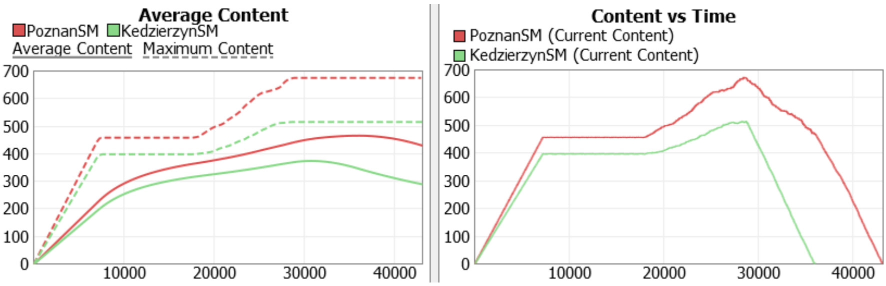

Fig. 2. Stock chart (average, maximum and time functions)

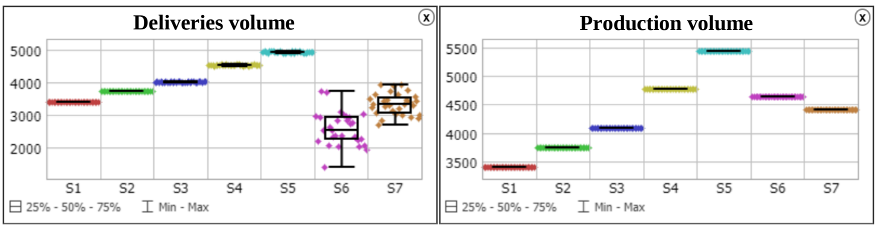

Fig. 3. Customer demand met within 12 hours and production volume

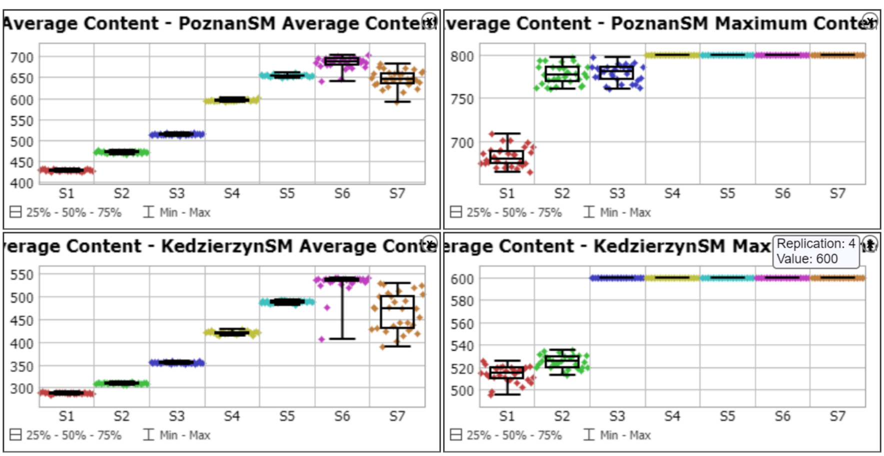

Fig. 4. Average and maximum filling of warehouses

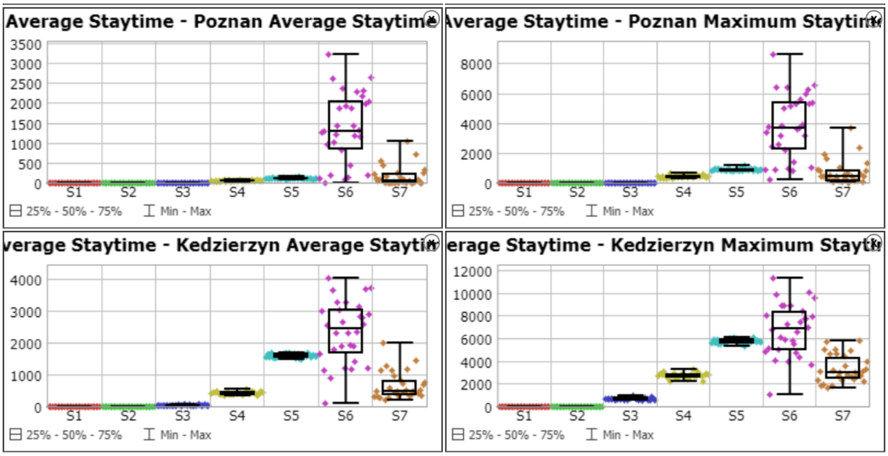

Fig. 5. The average time and the sum of the time the object is fully occupied

This article is limited to examining the above characteristics because they were considered representative for assessing the elasticity and sensitivity of the supply chain to changes in parameters. This allows the assessment of the goodness of the returned solution for the formulated decision problem and the method of its solution.

As the experiments show, deterministic variants with an equal production and notification intensity allow the delivery plan to be implemented in 12 hours. This applies to scenarios 1-4, but in scenario 5 the demand of about 500 units was not met. In turn, scenarios 3, 4 and 5 indicate flows that cause full utilization of the storage capacity, of course, this mainly concerns variant 5, here also the total time in which the object is filled is the most, i.e. 1h 40 min. Due to the provision of supplies that can meet the demand, full use of storage capacity is a common occurrence. With the Erlang distribution used for one of the replications, it is a total of over 3 hours in the warehouse in Kędzierzyn. Normal distribution is more stable in this respect. For the conducted research, there was no situation in which customer demand was not met. The stock level was set as the sum of expected value and standard deviation. Further, might be considered the reduction of inventory and testing more distribution samples, especially for the Erlang distribution, which has a large spread. Variant 6 shows significant fluctuations that can accurately map seasonality to products with a fast turnover and short life cycles. This is characteristic not only of the example above but should also be taken into account when forecasting and determining the statistical distribution describing demand.

Based on the conducted research, it is possible to select the distribution of probability that describes the demand without conducting detailed research and only based on knowledge of the industry, frequency of product rotation, and seasonality. This will be affected by an error, but it will allow presenting the behavior of the system.

5. Conclusions

Decision support in transport and storage activities is an integral part of logistics. Ensuring adequate efficiency of implemented processes is essential for each stakeholder and must be continuously monitored. However, mathematical models and optimization methods alone are not enough for policymakers. It is necessary to examine how the system will behave with implemented decisions when subjected to disturbances. It is the sensitivity test that allows answering the "what if" question and determines the flexibility of the system.

Research carried out in the article indicates the possibility of using the Flexsim environment to assess the sensitivity of solving the problem of the warehouse facility location. The solution obtained based on the SIMMAG3D methodology shows high resistance to disturbances, as well as to random changes in demand. It should be noted, however, that taking storage costs into account by senders could increase the storage facility capacity. Research using a simulation environment allows studying the level of inventory depending on various assumptions.

Future research in this area will also concern the developed methodology and simulation tests. Expansion with a detailed analysis of external transport and a longer time horizon is planned, it will also be necessary to implement the organization at the entry and exit of storage facilities.

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