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Modeling and planning of goods distribution logistics by logistics operators in the Middle Pomerania region

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Abstract

Nowadays, distribution logistics planning is based on integrated IT systems. These systems have a significant impact on the quality and efficiency of logistics processes at logistics operators. They enable the planning, coordination and control of logistics flows related to the flow of materials, finances and information throughout the supply chain in Middle Pomerania. The aim of this article is to model and plan distribution logistics from distribution centres in Middle Pomerania. The main research problem was formulated as follows: What models and methods of distribution logistics planning can ensure effective and flexible management of the flow of goods by logistics operators in Middle Pomerania, while reducing costs and ensuring high quality customer service? The following research gap was identified: despite numerous studies on distribution logistics at the national and metropolitan levels, there is a lack of comprehensive studies on the modelling and planning of distribution logistics in a regional context, especially in the area of Middle Pomerania. As a result of the change in the model, the time was reduced from 12 hours to 6.5 hours. Consequently, costs were reduced to PLN 481 (operating costs were maintained at the previous higher level of 30%), which significantly reduced the costs of parcel delivery and shortened delivery times in Koszalin and Slupsk. The analysis included: the concentration of parcel collection points into four areas A, B, C and D, delivery times and route optimisation.

Keywords: logistics distribution, route planning, logistics operations, delivery process, distribution process, logistics costs;

1 Introduction

The starting point for considering the issue of distribution and related customer service in distribution centers (DC), which is the subject of this paper, is an awareness of the role they play in the economy. The physical distribution of finished products has led to the integration of such departments within a company as distribution planning, order processing, and transport (Perano, Cammarano, Varriale, Del Regno, Michelino, & Caputo, 2023). This evolution also reflected the growing capabilities of telecommunications, infrastructure expansion, increased activity in the transport market following its deregulation, and the emergence of a real threat in the form of global competition. Distribution is responsible for delivering finished products to customers. Products flow from finished goods warehouses located at production sites through logistics operators' distribution centers to customers in sales markets (Freichel, Rütten, & Wörtge, 2022). In the warehousing and delivery process, it is important to respond to so-called sales peaks, or to speed up the delivery of goods from warehouses to customers (Živičnjak, Rogić, & Bajor, 2022). To this end, forecasting methods appropriate to the situation should be used. For short-term forecasting, the naive method and time series methods are definitely suitable (Bas, Egrioglu, & Kolemen, 2022). However, in situations where a decision on the quantity of goods to be transported must be made well in advance, such as in the case of high demand for a given product, when transport time is significantly extended, or when there is a lack of certainty regarding the continuity of supply, exponential smoothing methods should be used. The aim of this article is to model and plan distribution logistics from distribution centers in Middle Pomerania. The main research problem was formulated as follows: What models and methods of distribution logistics planning can ensure effective and flexible management of the flow of goods by logistics operators in the Middle Pomerania region, while reducing costs and ensuring high quality customer service? The following research gap was identified: despite numerous studies on distribution logistics at the national and metropolitan levels, there is a lack

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of comprehensive studies on the modeling and planning of distribution logistics in a regional context, especially in the area of Middle Pomerania.

2 Literature review

Outsourcing transportation services offered by logistics operators is a strategy in which a company decides to entrust the management of its transportation needs to external specialists or companies (Abbasi, Sıcakyüz, Gonzalez, & Ghasemi, 2024; Haglund, & Janné, 2024). This includes the transportation of goods, logistics planning, fleet management, and other transportation-related activities (Xu, Ning, Cheng, Zhang, Gao, & Huang, 2024). Outsourcing transportation services allows a company to focus on its core business while providing access to specialized knowledge and experience in the field of transportation, which can result in benefits such as reduced operating costs and optimized logistics processes (Akhtar, 2023). When configuring a distribution system tailored to the end customer's needs, it is essential to take into account time sensitivity and continuity of supply when selecting the right model (Sternberg, Mathauer, & Hofmann, 2023). Therefore, the proposed concept aims to centralize the flow of goods by using distribution centers and cross-docking warehouses (Lorenc, 2024). A logistics distribution center has been defined in literature as a center that coordinates logistics services and short- and long-distance transport, providing integrated transport connections along with the flow of information between manufacturers, distributors, and consumers, as well as a control system (Proença, Gaspar, & Lima, 2022). A logistics center has been defined as a spatially functional facility, together with its infrastructure and organization, in which logistics services related to the receipt, storage, distribution, and release of goods, as well as accompanying services, are provided by economic entities that are independent of the sender or recipient (Bachofner, Lemardelé, Estrada, & Pagès, 2022; Stopka, Droździel, & L'upták, 2022).

In the area of distribution, customer service standards that go far beyond the mere act of buying and selling are of particular importance. These standards relate to comprehensive and competitive after-sales service, including maintenance and warranty services, as well as ongoing marketing contacts with consumers (Liu, Yun, & Zhao, 2025). The role of the distribution system stems from the guiding principle of modern logistics, which states the need to shorten and accelerate all processes at every stage of distribution while maintaining the required quality of customer service (Wulandari, 2022). The main problem with distribution processes is that they are time-consuming due to the physical distance between the producer's market and the consumer's market (Putri, Arsyad, Dwivayani, & Boer, 2024). However, the longer the delivery time, the higher the delivery costs and, at the same time, the worse the customer service standards.

The most important costs associated with the implementation of logistics distribution processes are related to (Helo, & Thai, 2024; Cui, Qiu, Cao, Guo, Chen, & Gorbachev, 2023):

- supply of finished and cooperative products to the company – costs of physical flows of finished products in distribution channels from production to finished product warehouses and costs of flows of finished products from the manufacturer to the end consumer (wholesaler, intermediary, retailer), costs of order processing, handling, transport, remuneration,
- collection and storage of materials in finished product warehouses – costs of building and operating distribution channels in accordance with the adopted distribution system, costs of collecting and maintaining stocks of finished products in distribution channels, handling costs, final product packaging costs, storage costs, salaries,
- organization of the flow of materials from finished product warehouses to the end consumer - costs of handling information flows controlling the physical processes of finished product distribution, handling and transport costs, salaries.

The problem of physical distribution of goods (Modgil, Gupta, Stekelorum, & Laguir, 2022), products, and finished goods from manufacturers to end users should be considered holistically, in accordance with the logistical approach, as an important link in the logistical chain of material goods flow, in close connection with the accompanying information flows (Yang, Feng, & Qin, 2025). Distribution logistics integrates all physical processes and flows occurring in the sphere of sales and distribution into a single management system, whose main task is to minimize sales costs while maximizing the satisfaction of diverse customer needs (Judijanto, Asniar, Kushariyadi, Utami, & Telaumbanua, 2024; Ding, Wang, & Chan, 2023). The problem concerns the technology of moving goods – considering it from the moment the order is placed to the physical delivery to the recipient. The scope of distribution technology understood in this way includes warehousing, transport and handling processes, as well as packaging and methods and techniques for researching market needs (Adewusi, Chikezie, & Eyo-Udo, 2023). As a result of such a determined decision-making structure, the most important operational tasks in the field of distribution logistics include (Matwiejczuk, 2024):

- forecasting the primary demand of potential customers, shaping the physical processes of distribution of products and finished goods,
- selecting means of transport and optimal routes,
- determining optimal stocks in intermediate links of distribution channels,
- determining the number and length of distribution channels and the number of intermediate links, and planning their distribution.

The logistics distribution process, like other logistics processes, is subject to numerous risk factors (Ziari, & Taleizadeh, 2025; Celli, Pilo, Pisano, Ruggeri, & Soma, 2022). The most frequently mentioned risk factors in this area in the literature include (Frazier, & Lassar, 1996): long delivery times, poor (low) delivery readiness, low delivery reliability, high distribution costs, poor delivery quality, lack of knowledge of market niches, lack of funds for marketing research, problems with identifying key customers or buyer groups, inaccurate prediction of customer needs, inadequate level of service, errors in estimating customer profitability, errors in choosing a distribution channel management strategy, imbalance between customer expectations and the capabilities of all links in the supply chain, fads, volatility of demand, misunderstanding of market needs, lack of integration with customers, lack of or insufficient flow of information about demand from points of sale and key customers, inadequate methods of demand forecasting, competitive forces in the market, the impact of promotion and advertising, market potential, inflation, product substitution, volatility of legal regulations, the impact of promotion and advertising, the structure and strength of customers, employee qualifications and experience, employee shortages, failure to meet order deadlines, relations with contractors, failure to meet customer tastes, decline in the number of orders.

In the distribution planning process, planners receive the necessary information from other branches of the logistics operator and shipment senders (Bacchetti, Bertazzi, & Zanardini, 2021). When planning shipments, it is important to ensure smooth communication between the various parties involved in the planning process, including carriers who will deliver shipments to customers (de Mattos, Correia, & Kissimoto, 2024). It is often in the area of distribution planning that real challenges arise. Physical distribution may be handled by several different companies, and goods may change owners or carriers several times. Therefore, defining the rules of cooperation is often the result of a long process of clarification and agreement. An example of a specific solution in the field of distribution planning is VMI (Vendor Managed Inventory) – traditionally, demand is calculated by the recipient, in this case by logistics service providers (Lotfi, MohajerAnsari, Nevisi, Afshar, Davoodi, & Ali, 2024; Mohamadi, Niaki, Taher, & Shavandi, 2024). Similarly, shipment planning, which is normally the responsibility of the supplier, can be taken over by the recipient as a transferred freight charge (Jang, & Kim, 2026). Important organizational issues include the following (Rashid, Rather, & Hajam, 2023):

- scope of plans (planning horizon),
- frequency of analyzing and updating plans,
- planning time intervals (daily, weekly, or monthly).

When describing decision-making problems related to the design of the distribution planning process, it is also necessary to identify the most common variables that influence the adoption of certain solutions (Tian, Lu, Zhang, Zhan, Dulebenets, Aleksandrov, ... & Ivanov, 2023). An important variable influencing decisions regarding these and the previously described issues is the response time between the two links in distribution planning (Bouramdane, 2023). This variable is also related to: minimum delivery size and maximum delivery frequency, as well as response time, where barriers are high, e.g., minimum orders or when deliveries can only be repeated at long intervals (Wang, & Wang, 2022). In general, it can be assumed that short response times force planning to focus on the short term, without forgetting the longer planning period (Ryu, Chae, Kim, & Cho, 2025). When the response time is longer, the focus of planning shifts to more distant dates. This is simply because decisions made at short notice cannot significantly affect plans.

3 Research method

When configuring a distribution system, it is essential to adapt the distribution infrastructure to the physical location of customers/users. In order to select the optimal location for distribution centers and cross-docking warehouses, it would be necessary to analyze the current location of distribution centers (DC) in Middle Pomerania at the initial stage. This would make it possible to decide on the optimal location of transshipment warehouses, adjusting the result to the nearby transport network and the amount of space available for development. In the next stage, based on the designated locations of cross-docking warehouses in the territory, a central point (Koszalin or Slupsk) for Middle Pomerania would be determined, which would reflect the proposed location for the DC. When creating a distribution network model, it is necessary to locate the distribution infrastructure in relation to the dispersion of users. In the case under consideration, the distribution network of logistics operators acts as the recipient of transport services. The role of the transport service provider is performed by the transport infrastructure consisting of transport vehicles and using the existing transport route (road) structure. The task of the transport infrastructure is to balance the transport needs of the customer with the transport capabilities of the service provider. As part of the work, a model was developed that allows for mathematical analysis of the shipment flow tasks performed in it, taking into account a number of constraints in the distribution network and transport infrastructure. The model enables integrated problem solving in terms of allocation, portioning, routing, scheduling, and distribution of shipments with a specific freight charge and delivery within a specified time. The main research problem was formulated as follows: What models and methods of distribution logistics planning can ensure effective and flexible management of the flow of goods by logistics operators in the Middle Pomerania region, while reducing costs and ensuring high quality customer service? Detailed research problems were formulated as follows:

What are the transport market needs in distribution centers by logistics operators in the Middle Pomerania region?

What means of transport should be selected for individual shipments in the planning of goods distribution logistics by logistics operators in the Middle Pomerania region?

What are the most optimal routes for carriers delivering to customers of logistics operators in the Middle Pomerania region?

The following research gap has been identified: despite numerous studies on distribution logistics at the national and metropolitan levels, there is a lack of comprehensive studies devoted to modeling and planning distribution logistics in a regional context, especially in the area of Middle Pomerania. Fig. 1 shows a diagram of the process of calculating the distribution of shipments by carriers from the DC.

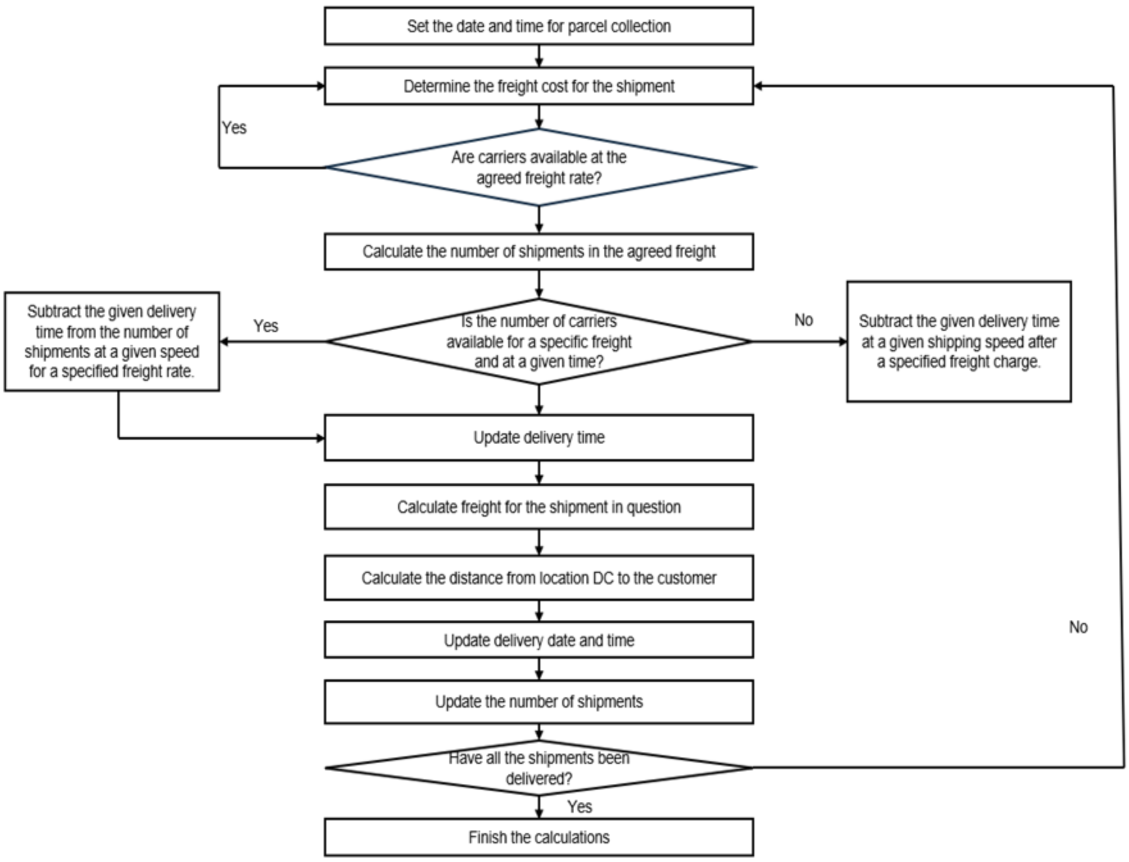

Fig. 1. Diagram of the process of calculating the delivery of shipments by carriers from the DC.

The problem of integrated shipment delivery scheduling and carrier routing has been formulated as a linear model. This model minimizes the completion times for all shipments while ensuring that they are delivered within a specified time frame. The constraints are: the number of available carriers, the capacity of logistics centers, the working hours of shipment recipients, and the opening and closing times of time windows in company warehouses. The following parameters were introduced in the mathematical description of the problem:

– t_z – loading time for one carrier,

– t_{pk} – travel time to recipient k (one way),

– t_{rk} – unloading time at the customer's premises k,

– $N1$ – a set of dates that make up the planning horizon; the difference between two consecutive dates is equal to the time step, $N_1 = \{1, \dots, n-1\}$

– N_0 – a two-element set of artificial terms responsible for introducing and removing all carriers from the model, $N_0 = \{0, n\}$,

– N – a set of all terms, $N = N_0 \cup N_1 = \{0,1, \dots, n\}$,

– K_0 – a set representing a distribution center, $K_0 = \{0\}$,

– K_1 – zbiór reprezentujący centrum dystrybucyjne, K_1=$\{1, \dots, m\}$,

– K – set of distribution centers and customers, $K = K_0 \cup K_1 = \{0,1, \dots, m\}$,

– R_k– set $n-1$ of number pairs (i, j) specifying possible start times for loading/return to distribution centers (since the model is deterministic, for a given distribution center k and for a given time step i there is only one possible date for returning to the distribution center $j = i + t_z + 2 \times t_{pk} + t_{rk} - 1$

– b – number of cars,

– h – delivery time,

– c – loading time expressed in number of unit periods,

– a_k – unloading time expressed in number of unit periods,

– d_k – customer demand k expressed in the number of periods required,

– T_i – term corresponding to the unit period i,

– q_k – client time window closing date k,

– g_k – start of operations of the distribution center k, expressed in the number of unit periods,

– B – a sufficiently large number.

The model also uses the following variables:

– x_{ijk} – A binary variable that is equal to 1 when the car left on time and arrived at the customer's location. k, and will return to the distribution center on time j (0 – otherwise), specified for $\forall_{i,j} \in N_1, \forall_k \epsilon K_1$,

– x_{ij0} – an integer variable expressing the number of carriers with vehicles waiting to be loaded at the distribution center (there may be several vehicles in the queue), determined for $\forall_{i,j} \in N, \forall_k \epsilon K_o$

– $y_{i,j,0}$– binary variable helping to model the condition of ensuring continuity of shipments,

– f_k – end of customer work k.

The mathematical model of the problem is as follows:

$$\min: Z = \sum_{k=1}^{m} f_k \tag{1}$$

with restrictions:

$$\sum_{j=0}^{n} \sum_{k=0}^{m} x_{ijk} - \sum_{l=0}^{n} \sum_{k-0}^{m} x_{lik} = \begin{cases} b & i = 0 \\ 0 & \forall i \epsilon N_1 \\ -b & i = n, \end{cases} \tag{2}$$

$$\sum_{j=1}^{n-1} \sum_{k=1}^{m} x_{ijk} \leq 1 \quad \forall i \epsilon N_1, \tag{3}$$

$$\sum_{(i,j)\epsilon R_k} x_{ijk} \geq d_k \quad \forall k \epsilon K_1, \tag{4}$$

$$f_k + t_{pk} \geq x_{ijk} \times T_j - B(1 - x_{ink}), \quad \forall i, j \ \epsilon N_1 \ \ \forall k \epsilon K_1, \tag{5}$$

$$f_k \leq q_k, \quad \forall k \epsilon K_1, \tag{6}$$

$$\sum_{i-l}^{l+a_k-1} \sum_{j=l+t_z+2\times t_{pk}+t_{rk}-1}^{l+t_z+2\times t_{pk}+t_{rk}+a_k-2} x_{ijk} \leq 1 \quad \forall k \epsilon K_1, \quad \forall l = 1, 2, \dots, n - a_k - t_z - 2 \times t_{pk} - t_{rk} + 1, \tag{7}$$

$$\sum_{i=l}^{1+c-1} \sum_{j=l+t_z+2\times t_{pk}+t_{rk}-1}^{l+t_z+2\times t_{pk}+t_{rk}+c-2} \sum_{k=1}^{m} x_{ijk} \leq 1 \quad \forall l = 1, 2, \dots, n - c - t_z - 2 \times t_{pk} - t_{rk} + 1, \tag{8}$$

$$g_k - t_z - t_{pk} \leq x_{ijk} \times T_i \quad \forall (i, j) \epsilon R_k, \ \forall k \epsilon K_1, \tag{9}$$

$$T_i \times x_{ijk} + h \geq T_v \times (x_{vjk} - y_{vjk}) \ \forall i, j = 1, \dots, n - h - 1, \forall v = 1, \dots, n \ \forall k \epsilon K_1, \tag{10}$$

$$x_{ijk} \geq y_{ijk}, \ \forall i, j \epsilon N_1, \ \forall k \epsilon K_1, \tag{11}$$

$$\sum_{(i,j)\epsilon R_k} y_{ijk} = 1, \ \forall k \epsilon K_1, \tag{12}$$

$$x_{ijk} \ \epsilon \{0,1\}, \quad \forall i, j \ \epsilon N_1 \quad \forall k \ \epsilon K_1, \tag{13}$$

$$x_{ij0} \geq 0, \quad \forall i, j \ \epsilon N, \tag{14}$$

$$y_{ijk} \ \epsilon \ \{0,1\}, \quad \forall i, j \ \epsilon \ N_1, \quad \forall k \ \epsilon \ K_1. \tag{15}$$

Function (1) minimizes the sum of delivery completion times to customers (total working time). Equation (2) is a flow equation and ensures that the available number of carriers is not exceeded. Condition (3) ensures that a maximum of one vehicle is loaded on time. Equation (4) ensures that the demand of each customer is met. According to condition (5), the completion times for all customers are calculated. Equation (6) ensures that the customer's work is completed before the time window closes. Constraint (7) eliminates queues at customers, and (8) ensures that the distribution center's capacity is not exceeded. Condition (9) ensures that the customer's work starts on time. Equations (10)-(12) ensure the continuity of shipments. FlexSim 3D Simulation Modeling and Analysis Software 2024 was used for the analysis.

4 Results

Typical values for a courier in urban traffic for the cities of Koszalin and Slupsk are a minimum of 100 shipments with 8–12 deliveries per hour, an average delivery time of 5–7 minutes, and a parking/walking time of 2–3 minutes, with an average speed in the city of 20–30 km/h due to the reconstruction and renovation of the main street in Koszalin and transport problems in Slupsk (access to the center). Therefore, after calculation, the distance between points is 0.8–1.5 km. The carrier delivers an average of 10 shipments/hour as a realistic average, which gives 10 hours. Loading + sorting should be added: 30–60 min and return to base: 20–30 min, which totals 11–12 hours of work. In practice, this means: 1 driver 1.5 days of work or 2 drivers -1 day. The cost for the carrier is PLN 40–55/hour, which gives 11 hours × PLN 45 ≈ PLN 495. Vehicle cost (fuel + depreciation + service): cost per 1 km: PLN 0.80–1.20, 100 km × PLN 1 ≈ PLN 100. Operating costs: usually: 20–30% of costs (planning, system operation, insurance, administration), which gives an average of PLN 120–180. The total cost of delivering 100 parcels by a carrier in the Koszalin and Slupsk area is between PLN 700 and PLN 800 (unit cost of the carrier PLN 7-8). Fig. 2 proposes changes to the delivery model.

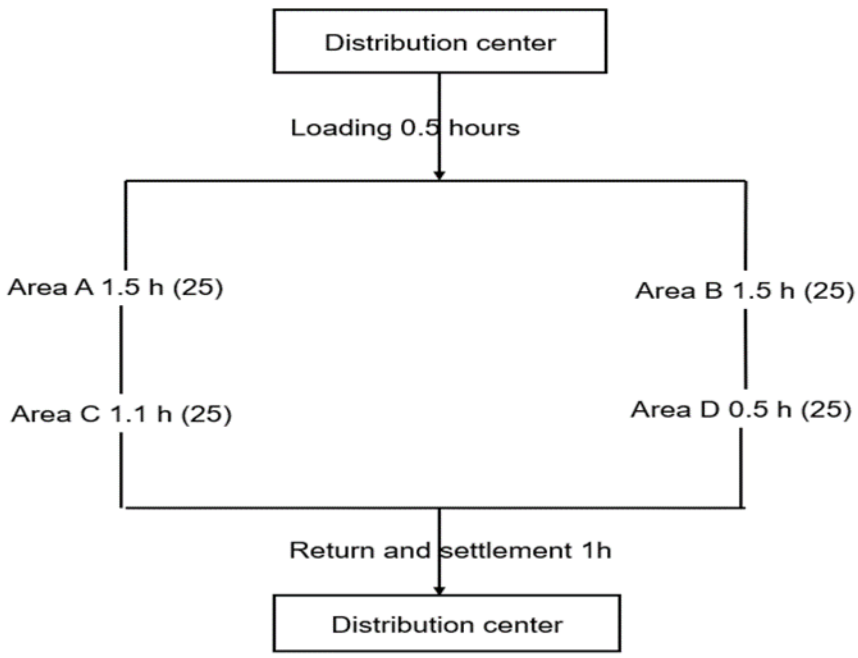

Fig. 2. Delivery model for carriers delivering parcels from DC.

When the parcel delivery model was changed, the time was reduced from 12 hours to 6.5 hours. As a result, costs were reduced to PLN 481 (operating costs were maintained at the previous higher level of 30%), which significantly reduced parcel delivery costs and shortened delivery times in Koszalin and Slupsk. The analysis included: the concentration of parcel collection points in four areas A, B, C, and D, delivery times, and route optimization.

5 Conclusions

Methods based on simulation modeling are certainly among the most frequently used and most effective tools for strategy verification and decision support. Practical observations, literature reviews, and analyses conducted by the author of this paper show that logistics processes are an area where there is still room for improvement. The rationalization of these processes, and in particular their optimization, could significantly reduce costs in transport companies carrying out transport processes for logistics operators. Firstly, modeling is a series of more or less complex methods, using mathematical and qualitative methods to support decision-making in the logistics industry. Secondly, modeling can be used in all elements of logistics where knowledge about future customer behavior, their needs, and trends is needed. Modeling is also necessary to determine the quantity of goods, the place, and the time when there will be demand for them. Thirdly, almost all models that work in practice are used in distribution logistics. Fourthly, models should be preceded by a very thorough analysis of the entire environment. Several elements should be taken into account, including the type of logistics operator, its location, and the processes that take place in its distribution center. Depending on these factors, a model for the delivery of shipments is selected by the transport companies serving customers on behalf of the logistics operator. It is difficult to formulate universal recommendations, because the choice of a specific model should be linked to the conditions resulting from the specific nature of individual industries and customer service standards. In order to maintain the greatest possible versatility of shipment delivery, it is not possible to consider proposing ready-made models. The article achieved its goal, which was to model and plan distribution logistics from distribution centers in Middle Pomerania using the example of two major cities, Koszalin and Slupsk. The distribution logistics planning model presented in the article ensures effective and flexible management of the flow of goods by logistics operators in the main cities of Middle Pomerania, while reducing costs and ensuring high-quality customer service. As a result of the research, the same means of transport were used in a shorter time, which may increase their demand in distribution centers for the collection of shipments in the area of Middle Pomerania. The analysis took into account the means of transport available to logistics operators for individual shipments in the planning of goods distribution logistics in the Koszalin and Slupsk areas. Routes were selected and changed for carriers delivering to customers of logistics operators in the Koszalin and Slupsk areas. The research gap concerning research and optimization of distribution logistics in a regional context in the Middle Pomerania area was filled. The analysis covered the logistics cost ratio, taking into account the breakdown of logistics costs. Logistics determinants, such as effective distribution logistics management and optimal transport planning, are crucial to the effectiveness of the distribution process. The findings of the study have important implications for business practice, as they point to the need to consider both customer service and logistical factors when developing goods distribution planning by logistics operators.

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