Distribution center logistics optimization model – City of Rijeka case study

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ABSTRACT

The optimization of the goods delivery to Rijeka's city center presents a complex organizational framework where many parameters must be taken into account and a diverse multi-methodological approach, needs to be utilized. The building of a distribution center is asserted here to be one notable way to improve the existing delivery service. The grouping of freight in a distribution center would result in a reduction of transport costs due to a smaller number of vehicles entering the city center, in turn reducing the traffic burden incumbent on the city's transport network. In this paper, two of the many possible methods related to the optimization of goods delivery in city centers, have been used. Based on the data collected through the study's questionnaire, conducted in the area of the city of Rijeka, the method of gravity center has been used to determine the location of the distribution center. Then, based on the tentative location of the distribution center, the method of optimization of the transport process has been applied by resorting to transport problem-solving methods, including several different implementation scenarios. From the proposed solutions, and based on the results detailed, the solution that was found to be the most credible was arguably the best match with the default criterion.

ARTICLE INFO

1 Introduction

The organization of transport within the city center has a significant impact on the sustainability and structure of the city area. Today's traffic in city centers takes place in a way that each carrier determines for himself the time and routes by which he will deliver [1]. Therefore, it is necessary to properly organize the goods delivery to city centers to increase the productivity and effectiveness of logistics service providers, improve service to end-users, reduce the number of transfers and deliveries by stores, and facilitated transport of goods to the city center [2]. One way to optimize delivery in city centers are distribution centers. Distribution centers represent a central point in the transport chain, which would significantly reduce the number of delivery vehicles that would deliver to the city center [3].

Most of the problems that occur in the supply chain can be globally resumed to problems of optimization of certain activities and processes that have more than one solution.

It is necessary to choose that solution, which according to defined criteria, mostly or fully satisfies the set constraints [4]. Using the previously defined theory, the biggest problem represents the choice of the location of a distribution center that must meet the needs of all interest groups according to defined criteria. The globalization process has resulted in an increasing demand for consumer goods consumption, thereby causing an increase of the market concentration of products which represent competition to each other thus increasing competition among companies [5]. The mentioned problem of increasing economic entities is dependent but also sustainable only through a good organization of the delivery transport activities to economic entities that are the last contact of the supply chain prior to the final use of the products by end customers. By using the methods of the operational research in the transport sector, the emphasis has been put on optimization procedures, and in this concrete example, on the optimization flows of goods to the city center [6]. The goal

of the paper is to propose and apply modem that will optimize the activities of delivery of goods to economic entities in the city center by using scientific methods.

2 Theoretical background

The problems of city logistics occur due to the growing quantities of goods within the city area. According to the Institute for City Logistics, city logistics is a process of fully optimizing logistics and traffic activities of private companies in city areas with regard to traffic environment, traffic congestion, and energy consumption within the market economy [7]. The goal of city logistics is to achieve optimal distribution of goods in city centers taking into account the quantity of transport of goods, reduce traffic congestion and thereby mitigate harmful impacts on the environment [8]. Comprehensive planning and management of public transport is necessary for the sustainability of the center, resulting in a reduction in transport costs and a higher level of logistics services, which makes the city center cleaner and safer for residents [5][9][10]. Distribution centers increase the amount of transported goods in vehicles that enter a particular city area, thus reducing unit transport costs, reducing the number of deliveries to be made for one location, reducing delivery time [11]. When delivering goods to city centers, carriers plan routes in advance keeping in mind that locations are often not connected, or they are located at different locations [7]. The distribution of goods in the city center is significantly influenced by e-commerce. Purchasing via e-commerce increases significantly, which increases the volume of freight traffic to the city center, resulting in more traffic congestion towards the city center. Delivery to your home address can and must be part of the concept of city logistics [4][1]. The goal is to better utilize the capacity of freight vehicles in order to reduce the number of vehicles that enter the city centers which greatly facilitates distribution centers [12]. Centers for the distribution of goods would also become a concentration point in the transport chain. Linking with distribution centers is a hope that cargo traffic within urban areas can be significantly reduced. Especially the recipient problem can be applied, which has no coordinated logistics and causes many trips [13] [14]. Distribution centers can be used to reduce or eliminate a certain number of heavy freight vehicles that enter certain parts of the city [3]. The key aspiration is to use the full capacity of freight vehicles, as well as to achieve economic benefits and benefits to the environment [15]. Huang et al. [14] have chosen the method of gravity center to get the optimum location of the distribution center and made a comprehensive analysis of the actual situation, and then there was a place for the optimal location of the center in northern China. Also, Thai et. al [15] chose method of gravity center when developing a study to create distribution center on the example Nordic case study. Optimization of transport to the city center can be optimized by using the methods of operational research to solve transport problems [16][17]. Grazia Speranza [18] in his work points out that the methods of operations research gave a fundamental contribution to the supply chain management and solving transportation problems.

3 Delivery activities optimization models

Defining the model for optimization of delivery activities and its implementation comprises two interconnected phases. The first phase of the model refers to the application of the method for selecting a potential location for the construction of the distribution center, while the second phase based on the proposed location solution includes the simulation of the goods delivery scenarios from the starting point to the destination [19]. The difficulty of choosing a location of a distribution center is an extensive activity due to all relevant criteria that affect its location, and hence its future operations [20]. When building a distribution center, you need to take several potential scenarios into account and choose one of them that best meets the criteria [21]. One of many methods of choosing a location is the method of gravity center that belongs to the group of location-statistical methods. The goal of this method is to choose the optimal location as a center of logistics activities which will offer the best ratio between total transport costs of the distribution center and spatial distance from the distribution center to economic entities [22]. The problem of traffic congestion and non-coordination of deliveries in peripheral areas of the city is not so distinct and attractive for analysis and observation as the problem of the city center itself. In the optimization of delivery operations, it is necessary to analyze, but also to collect data about the supply and demand of the carriers respectively economic entities i.e. recipient of goods and then analyzed in detail in order to detect the interdependence of these two groups of distribution chain members [10]. Solve the problem of optimizing transport activities using the logic of transport problems is one of the options of optimizing goods delivery in the city center [6]. The optimization of goods delivery flows will be presented by the mathematical transport problem model depending on the starting point/destination and transport costs that appear at certain distances between the starting point and the destination. The proposed model can be improved by using simulation tools. The development of a simulation model at the macro or micro level enables the introduction of dynamism into the model respectively stochasticity of traffic flows i.e. transport network. In this way, the real state of realization of delivery activities is achieved. The application of microscopic simulation models enables the analysis of traffic congestions, vehicle travel time to the delivery point, the estimation of the amount of harmful gases generated by vehicles in the transport network, etc. On the other hand it requires the identification of numerous input parameters and their attributes, which in many situations are difficult to define precisely. By analyzing the microscopic model of delivery activities, it is possible to identify limitations, but also problems that cause inefficiency in their implementation. The inefficiency in the delivery

activities can be attributed to the delay of vehicles, which occurs due to the interruption of the continuous realization of traffic flows or due to the existence of traffic regulation facilities and due to the existence of different dynamics of movement and the behavior of vehicles in the transport network. According to the researched scientific literature, the data that can be applied in the methodology to determine the optimal location of distribution centers, as well as the optimization of delivery activities, are defined and analyzed.

3.1 Method for choosing the location of a distribution center

Method of gravity center is used independently as a method for determining the location if we speak of a location of one object or as a first approximation method in other sophisticated models that solve more complex problems of determining a location. Each mathematical-statistical method has advantages and certain shortcoming. The method of gravity center is easy to apply, but the disadvantages are manifested in the way that it does not take into account certain parameters, such as the infrastructure system, labor and inventory costs and other elements that are relevant in assessment of the location choice [16]. When using this method, it is necessary to define the appropriate input data such as X and Y coordinates, the volume of goods being transported and unit transport cost per kilometer distance [23]. The distance (d_i) between individual transport companies to the gravity center and every boundary point can be expressed by applying the Pythagorean theorem or Euclidean metric. The expression for distance calculation follows [24]:

$$d_i = K \cdot [(\bar{X} - X_i)^2 + (\bar{Y} - Y_i)^2]^{\frac{1}{2}} \qquad (1)$$

With:

d_i – the distance from the point to the gravity center

X, Y – the gravity center coordinate

X_i, Y_i – point coordinates and

K – unit value in the coordinate system.

By determining the location of the distribution center as it has been said above, it is necessary to define several alternative solutions in the model in order to optimize the optimal location of the distribution center based on the minimum cost criteria. The expression that is used to determine the total cost of delivering goods from carriers to the distribution center is as follows [16]:

$$min\, TC = \sum_{i=1}^{N} V_i \cdot R_i \cdot d_i \qquad (2)$$

With:

TC – total cost of transport

N – number of points (units of economic activities)

V_i – volume of goods

R_i – unit transport cost

d_i – the distance from the point to the gravity center.

Taking into account all the above, it is concluded that for the optimal distribution of goods it is necessary to build and integrate a distribution center into the supply chain, whereby the choice of the location represents a preliminary but also a crucial step in solving the problem.

3.2 Delivery optimization methodology

Problems of optimization of transport activities are solved through numerous scientific methods depending on their suitability for use in a particular area. The logic of solving the problem of transport activities by means of transport problems is offended within the transport sector as the most appropriate method for optimizing various activities as well as traffic [19]. Within Chapter 4, the logic of transport problems was applied in optimizing delivery activities in a way that transport problems were solved separately in two interdependent phases to simplify the studied work problem and to simplify the process of finding the optimal solution. Optimization of delivery activities within the work implies optimization of the cost of delivery activities, with the aim of minimizing the total costs of the first and second phases of transport problems. When forming a transport problem, it is necessary to determine the starting point and destination of transport activities and their supply and demand, but also the transport costs depending on the distance between the mentioned starting point and the destination [21]. In the global view, the goal of the method is to simulate the flows of goods delivery from the starting point to the destination, under the condition that the goal function i.e. the total costs of delivery are minimal, which is also one of the most common conditions of transport activities of the goods delivery [17]. The general form of the goal function can be shown by the following expression [20]:

$$minF = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}x_{ij} = a_{11}x_{11} + a_{12}x_{12} +$$
$$+ a_{13}x_{13} + a_{21}x_{21} + \cdots + a_{ij}x_{ij} \qquad (3)$$

When choosing an optimal location of the distribution center, and under the condition that the delivery costs of daily claims for goods are minimal as is shown in expression (3), it is necessary to compare the different delivery scenarios (delivery costs) of the transport problem depending on the presumed location of the distribution center.

4 Implementation of the model and analysis of the results of the optimization of delivery activities – case study of the City of Rijeka

In selecting the location and flow optimization of delivery of goods, the data of two groups of mutually dependent stakeholders within the logistics chain were used. One
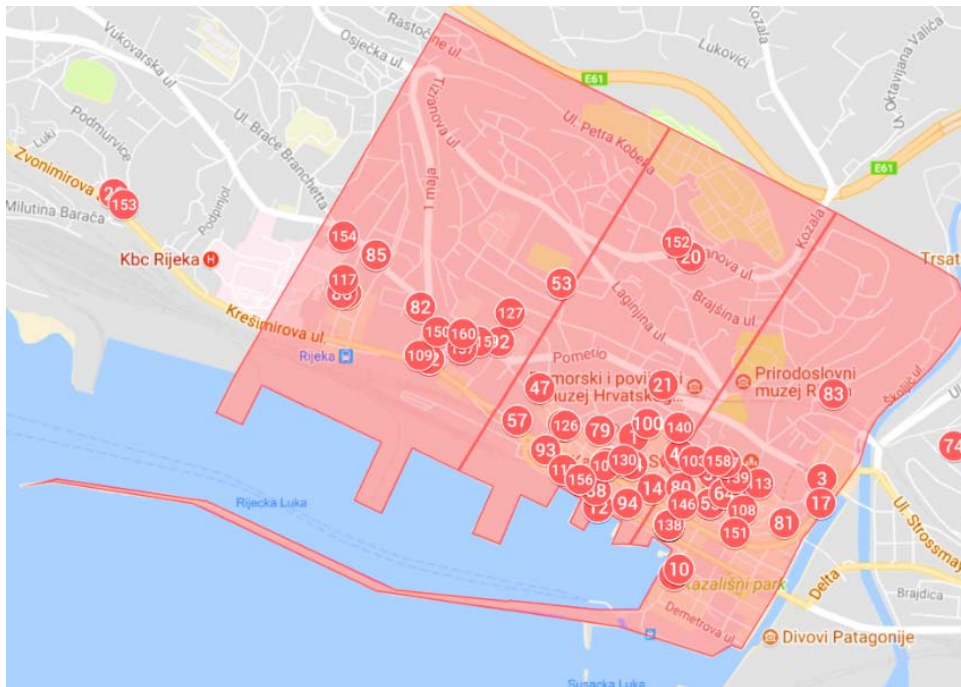
Figure 1 Economic entities grouped into Zones 1, 2, and 3

Source: Created by authors by locations of surveyed entities using Google maps; (https://www.google.com/maps/)

group of stakeholders represents transport companies that make up a supply of transport services of goods, while another stakeholder group represents economic entities that demand goods of a wide range of usage in a highly concentrated urban area [25].

The collection of data needed to set up the model was done through questionnaire forms, specially formulated and adapted for each of the stakeholder groups integrated within the logistics chain. The questionnaire form used to collect data on transport companies consists of a total of 33 questions distributed within six groups of questions: 1. General information about the legal entity, 2. Transport activity, 3. Data about the delivery route, 4. Data about the frequency of transportation, 5. Delivery information and 5. Problems and suggestions. Each of the above set of questions includes 2 to 8 sub-questions that can be answered by multiple choice of offered solutions or to enter the answer independently. The form was completed in total by 28 transport companies, which, according to the criteria of the frequency of delivery activities, largely burden the delivery vehicles with the center of Rijeka. The survey form for a group of economic entities involved in the realization of transport activities consists of 129 sub-questions within four groups of questions: 1. General information about commercial activity, 2. Supply process, 3. Description of delivery to the final customers and 4. Problems and suggestions. The survey questionnaire relating to a group of economic entities was filled by 244 economic entities concentrated in the narrower urban area. According to the analysis of the survey

questionnaire results, surveyed economic entities that generate demand for goods delivery services to the city center, to simplify the problem, are spatially distributed and grouped into three areas i.e. the zone as shown in Figure 1.

The second group of surveyed entities refers to transport companies that deliver in a wider area of Rijeka. Surveyed carriers have a large vehicle fleet where the vehicles they own are classified into three categories depending on vehicle mass vehicle category less than 1.5 tons, vehicle category from 1.5 to 3.5 tons, and vehicle category greater than 3.5 tons.

4.1 Determining the location of the distribution center

The application of the method of gravity center, which represents the first phase of the optimization model of delivery activities, is based on the expression (2), which requires the analysis of the questionnaire forms to collect the appropriate input parameters. The surveyed 28 transport companies are grouped into 11 groups considering their extremely small distance between the city of Rijeka. The volume of goods transported by transport companies, the unit transport cost and the distance of transport companies to the city center are the input data necessary to apply the method of determining the location of the distribution center. Based on the above mentioned input parameters, the application of the method for determining the position of the distribution center in the area of Rijeka is shown in Table 1.

Table 1 Implementation of center gravity method in order to locate the optimal location of the distribution center

Carriers	X_Coordinates	Y_Coordinates	Volume [kg]	Unit transport cost/km (kn)	Distance (km)	Total Costs (kn)
A	45.3517509	14.3687357	1,000	7.79	14.25933706	111,175.29
B	45.3253887	14.4718616	4,500	7.79	3.712167035	130,241.38
C	45.3362725	14.5059251	14,000	9.70	1.074741318	146,025.10
D	45.3422445	14.4231524	1,600	5.67	8.735608601	79,249.44
E	45.3259608	14.5089916	5,200	12.05	0.001474447	92.38
F	45.3253887	14.4718616	1,800	12.05	3.712167035	80,516.90
G	45.3259608	14.5089916	18,000	7.79	0.001474447	206.92
H	45.3422445	14.4231524	3,000	9.70	8.735608601	254,337.24
I	45.3362725	14.5059251	1,500	7.79	1.074741318	12,569.09
J	45.3259608	14.5089916	1,500	5.67	0.001474447	12.54
K	45.3422445	14.4231524	200	5.67	8.735608601	9,906.18
	X	Y			Ukupno (kn)	824,332.50
Distribution center	45.325968	14.50897875				

Source: Created by authors according to collected data from survey forms

The optimal location of the distribution center is the one in which the sum of the transport costs between the transport companies and the generated location of the distribution center is the smallest. By an iterative procedure for implementing the method and taking into account the input data that delegate the location of the distribution center, the obtained location is located at coordinates X=45.325968 and Y=14.508979. By entering the coordinates on the GIS platform, it is shown, that the location of the distribution center is located in the area of the industrial zone Kukuljanovo. By determining the location of the distribution center as it has been said above, it is necessary to define several alternative solutions in the model. For mentioned alternative solutions the locations of distribution centers in the area of Sušak (street Ivana Matrljana) and in the area of Delta where Export Drvo d.o.o. is located are chosen. These locations meet the distance criteria but also the criteria of available space intended for building a distribution center. Figure 2 shows the geographic solutions obtained by implementing the first phase of the optimization of delivery activities and the two alternative solutions.
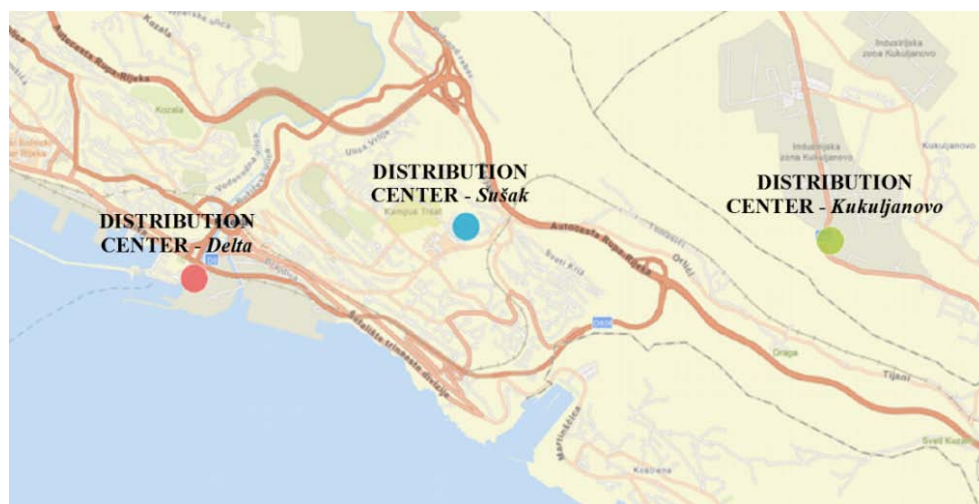

Figure 2 Optimal solution of location of the distribution center and the proposed alternatives

Source: Created by authors by defined locations of distribution centers using PowerBI v2.58.5103.501., ArcGIS Pro i Autodesk AutoCAD 2016

4.2 Optimization of delivery activities based on construction and integration of distribution center

The last phase of optimization process relates to the application of transport problem methodology. The application of logic of transport problems represents the last phase of the optimization of delivery activities to the city center. The method used above, for determining the potential location of the distribution center and the proposed alternative distribution center location was taken into account in the application of this method as a separate destination/origin in the process of delivering goods to the city center. The model of each transport problem is defined as a two-phase transport problem precisely because of the integration of the distribution center as the destination/origin in the process of delivering goods.

For the implementation of the second phase of the delivery activities optimization model, it is necessary to define input data such as:

– quantity of the goods requested,

– quantity of offered goods, and

– unit transport costs per kilometer distance for each category of vehicle used by carriers.

The quantity of requested/offered goods was obtained based on the questionnaire forms provided for each group of stakeholders. The unit transport costs necessary for the execution of delivery activities are determined based on research and assessment of the transport services market depending on the vehicle category of the transport companies which are the following:

– vehicle category less than 1.5 tons = 3.98 kn/km,

– vehicle category from 1.5 to 3.5 tons = 7.36 kn/km,

– vehicle category above 3.5 tons = 12.05 kn/km.

The transport costs for the first and second phase are obtained by multiplying distance and unit cost per kilometer for each of the above categories of vehicles which are available to each of the group of carriers. The input data of the first and second phases of the transport problem are shown in Table 2 and 3.

It can be concluded from Tables 2 and 3 that the offer of goods to carriers is higher than the demand for distribution centers, which means that the first phase of the transport problem is an open transport problem, while in the same way, the distribution of distribution centers in the second phase is equal to the demand of economic entities in the zones 1, 2 and 3 resulting in the ambition to minimize the required storage space of the distribution center to the delivery of the exact quantity of goods intended for the needs of economic entities. Based on the input data and applying the logic of transport problems within the model of the optimization of delivery activities, the calculation scenarios were carried out by integrating the distribution center within the model of delivery activities for all three construction sites.

The iterative implementation of the calculation shows that the location of the distribution center in the Sušak area best meets the defined criterion of the minimum total cost of delivery activities with respect to the set limits. The first phase goal and restriction function ($F_{(1)}$) of the optimal transport problem solution according to the data from

Table 2 Input data of the first phase of the transport problem model

From (Carriers)/To (Distribution Center)	Sušak	Kukuljanovo	Delta	Supply
Tome Strižića St.	0.55 km/4.29 kn	7.30 km/56.92 kn	3.20 km/24.95 kn	6,300
Osječka st.	6.20 km/48.34 kn	14.30 km/111.49 kn	3.70 km/28.85 kn	4,800
Kukuljanovo	7.50 km/58.22 kn	0.15 km/1.17 kn	10.30 km/80.31 kn	40,200
Tina Ujevića st.	10.90 km/84.99 kn	18.00 km/140.34 kn	8.30 km/64.71 kn	1,000
Demand	3,039	19,392	2,798	

Note: *Demand and Supply data are shown in kilograms

Source: Adapted by authors according to the results obtained using WinQSB v2.0

Table 3 Input data of the second phase of the transport problem model

From (Distribution Center)/To (Zone)	Zone_1	Zone_2	Zone_3	Supply
Sušak	3.90 km/30.41 kn	3.60 km/28.07 kn	3.90 km/30.41 kn	3,039
Kukuljanovo	12.10 km/94.34 kn	10.40 km/81.09 kn	10.60 km/82.64 kn	19,392
Delta	1.40 km/10.92 kn	1.00 km/23.39 kn	1.40 km/10.92 kn	2,798
Demand	3,039	19,392	2,798	

Note: *Demand and Supply data are shown in kilograms

Source: Adapted by authors according to the results obtained using WinQSB v2.0

Table 2, where it is necessary to transport goods from transport companies to the distribution center reads:

$$(S1)minF_{(1)} = 4.29x_{11} + 48.34x_{21} + 58.22x_{31} + 84.99x_{41} \quad (4)$$

Constraints are:

$$x_{11} \leq 6,300 \text{ kg}; \ x_{11} + x_{21} + x_{31} + x_{41} = 25,229 \text{ kg}$$
$$x_{21} \leq 4,800 \text{ kg}$$
$$x_{31} \leq 40,200 \text{ kg} \quad (5)$$
$$x_{41} \leq 1,000 \text{ kg}$$

By solving the first phase of the optimal solution, the following results were obtained.

According to Table 4 the distribution of 6,300 kg of goods from carriers located in Tome Strižića street, 4,800 kg of goods from carriers located in Osječka street and 1,429 kg of goods from carriers located in the area of Kukuljanovo to the distribution center – Sušak is ordered. The goal function in relation to the distribution flows of transported goods is:

$$(S1)minF_{(1)} = 4.29 \cdot 6,300 + 48.34 \cdot 4,800 +$$
$$+ 58.22 \cdot 14,129 = 1,081,649.38 \text{ kn} \quad (6)$$

The solution of the second phase of the transport problem refers to the goods delivery from the distribution center – Sušak to zones 1, 2, and 3 (economic entities) located in the city center. The goal function and the constraints of the second phase of the transport problem ($F_{(2)}$) according to the data in Table 3 is:

$$(S2)minF_{(2)} = 30.41x_{11} + 28.07x_{12} + 30.41x_{13} \quad (7)$$

Constraints are:

$$x_{11} \leq 3,039; \ x_{11} + x_{12} + x_{13} = 25,229$$
$$x_{12} \leq 19,392 \quad (8)$$
$$x_{13} \leq 2,798$$

By an iterative solution of the second phase of the transport problem, the following solution was obtained.

According to the results from Table 5, it is stated that the optimization flows of the goods delivery to the city center i.e. in zones 1, 2 and 3 requires the transport of 3,039 kg of goods from the distribution center – Sušak to zone 1, 19,392 kg of goods to zone 2 and 2,798 kg of goods to zone 3. The goal function of the second phase of the transport problem is:

$$(S2)minF_{(2)} = 30.41 \cdot 3,039 + 28.07 \cdot 19,392 +$$
$$+ 30.41 \cdot 2,798 = 721,836.63 \text{ kn} \quad (9)$$

The total costs of optimizing the delivery activities of the first and second phases of the transport problem provided the construction of a distribution center in Sušak area are:

$$minF_{total} = (S1)minF_{(1)} + (S2)minF_{(2)} =$$
$$= 1,081,649.38 \text{ kn} + 721,836.63 \text{ kn} = \quad (10)$$
$$= 1,803,485.99 \text{ kn}$$

Table 4 Results of optimization of delivery activities for the first phase of the transport problem

	From (Carriers)	To (Distribution Center)	Shipment	Unit_Cost	Total_Cost	Reduced_Cost
1	Tome Strižića st.	Sušak	6,300 kg	4.29 kn	27,027.00 kn	0 kn
2	Osječka st.	Sušak	4,800 kg	48.34 kn	232,032.00 kn	9,536743E-07 kn
3	Kukuljanovo	Sušak	14,129 kg	58.22 kn	822,590.38 kn	9,536743E-07 kn
4	Kukuljanovo	Unused_Supply	26,071 kg	0 kn	0 kn	0 kn
5	Tina Ujevića st.	Unused_Supply	1,000 kg	0 kn	0 kn	0 kn
Total		**Objective**	**Function**	**Value =**	**1,081,649.38 kn**	

Source: Adapted by authors according to the results obtained using WinQSB v2.0

Table 5 Results of optimization of delivery activities for the second phase of the transport problem

	From (Distribution Center)	To (Zones)	Shipment	Unit_Cost	Total_Cost	Reduced_Cost
1	Sušak	Zone 1	3,039 kg	30.41 kn	9,415.99 kn	0 kn
2	Sušak	Zone 2	19,392 kg	28.07 kn	544,333.44 kn	0 kn
3	Sušak	Zone 3	2,798 kg	30.41 kn	85,087.18 kn	0 kn
Total		**Objective**	**Function**	**Value =**	**721,836.63 kn**	

Source: Adapted by authors according to the results obtained using WinQSB v2.0

For the purpose of increasing the statistical reliability of the results, the calculation for the remaining two scenarios of integration of the distribution center into the supply chain in the area of Kukuljanovo and Delta was carried out. Solutions for the transport problem optimization of delivery activities for the remaining two scenarios (Phase 1 and 2) are presented in Table 2 and 3.

According to the solutions of the first (Table 6) and second (Table 7) phases of the transport problems, the total cost of delivery activities if the construction of the distribution center in the area of Sušak is started is 1,803,485.99 kn. The ratio of the total cost of delivery activities during the construction of the distribution center in Sušak and the total cost of delivery activities based on the construction of the distribution center in the area of Kukuljanovo (2,119,941.15 kn) points out that the construction and integration of the distribution center in Sušak area is justified by 15%. It is also noticeable that the largest quantity of goods transported by transport companies from the Kukuljanovo area, which in the first phase of the transport problem of this scenario resulted in minimal cost of delivery activities due to smaller distances, but the dislocation of the Kukuljanovo distribution center and economic entities in zones 1, 2 and 3 greatly increased the total cost of delivery in the second phase of the transport problem, which represents the ratio of the total cost of delivery activities of the first and second phases of the transport problem of 1:99. Comparing the selected optimum location of the distribution center with the last tested scenario (Delta Distribution Center) where it is evident that the total cost of deliveries of the first and second phases of the transport problem in the amount of 1,932,083.92 kn is only 7% higher than the total cost delivery activities of the selected optimum scenario. The difference between the total cost of the optimal solution and the last scenario is their small interdependence and the equal distance between the transport companies and the economic entities in zones 1, 2, and 3. Due to the above, there is no large difference in the cost of delivery activities as observed in relation to optimum solution and the second scenario. The ratio of the total costs of the first and second phase of the transport problem of the last scenario is 73:27. The disparity of the relationship is the result of a greater distance of the first phase of the transport problem due to the location of the distribution center in the Delta area (the center of the city of Rijeka) but also a smaller distance in the second phase of the transport problem than the distribution center and economic entities located in the city center. As already stated that the total cost of delivery activities of the selected optimum solution and the third scenario are not very different, the author's assessment found that due to better transport connectivity (connection to bypass roads and the vicinity of highway connections) and a larger spatial surface area for the realization of construction and integration of the distribution center into the supply chain, the first tested scenario for locating the distribution center in Sušak area is a more acceptable solution.

Table 6 Results of all three solutions of the optimization of delivery activities (Phase 1)

From (Carriers)/To (Distribution Center)	Sušak	Kukuljanovo	Delta
Tome Strižića st.	6,300 kg/ 27,027.00 kn	0	6,300 kg/ 157,185.00 kn
Osječka st.	4,800 kg/ 232,032.00 kn	0	4,800 kg/ 138,480.00 kn
Kukuljanovo	14,129 kg/ 822,590.38 kn	25,229 kg/ 29,517.93 kn	13,129 kg/ 1,054,390.00 kn
Tina Ujevića st.	0	0	1,000 kg/ 64,710.00 kn
Total	**25,229 kg/ 1,081,649.38 kn**	**25,229 kg/ 29,517.93 kn**	**25,229 kg/ 1,414,765.00 kn**

Source: Adapted by authors according to the results obtained using WinQSB v2.0

Table 7 Results of all three solutions of the optimization of delivery activities (Phase 2)

From (Distribution Center)/ To (Zone)	Zone_1	Zone_2	Zone_3	Total
Sušak	3,039 kg/ 92,415.99 kn	19,392 kg/ 544,333.44 kn	2,798 kg/ 85,087.18 kn	25,229 kg/ 721,836.61 kn
Kukuljanovo	3,039 kg/ 286,699.25 kn	19,392 kg/ 1,572,497.25 kn	2,798 kg/ 231,226.72 kn	25,229 kg/ 2,090,423.22 kn
Delta	3,039 kg/ 33,185.88 kn	19,392 kg/ 453,578.88 kn	2,798 kg/ 30,554.16 kn	25,229 kg/ 517,318.92 kn

Source: Adapted by authors according to the results obtained using WinQSB v2.0

5 Conclusion

The implementation of the research on delivery activities in the city of Rijeka resulted in the perception of a growing problem in the delivery of goods to the city center. Variants of models and phases of solving problems nowadays are increasingly numerous. However, the proposed model of the optimization of delivery activities in this paper is highlighted by the implementation of the optimization in two interconnected and dependent phases. The implementation of the first phase of the optimization of delivery activities in which the quantitative method of gravity center was used, resulted in obtaining the optimum location of the distribution center in the area of the city of Rijeka. The most significant advantage in the application of the model of gravity center is its simple use in order to make decisions about the optimal location of the distribution center with acceptable errors respectively variations in the determination of the location. The reason for this is that the existing locations of the observed entities are taken into account, whereby the optimal location of the distribution center is the one that with minimal cost takes into account the minimum weighted distance between the distribution center and economic entities within individual zones. The optimum location of the distribution center was obtained in the immediate vicinity of the city area, i.e. in the area of Kukuljanovo. This location is the result of the main goal of minimizing the cost of delivering goods based on the shortest distances, quantity of transported goods and transport costs per kilometer of distance. In order to increase the statistical reliability, with the optimal solution, two alternative solutions (distribution center Sušak, Delta distribution center) were also proposed. The basis for the implementation of the second phase of the optimization of delivery activities is the first phase solution, assuming the integration of the distribution centers at different locations in the supply chain. By applying the methods of operating research by calculating all three scenarios depending on the location of the distribution center, the results of the optimization of delivery activities were obtained. The construction of the distribution center in the area of Sušak meets the criterion of minimum total delivery costs by 15% in relation to the optimal solution obtained through the first phase of the optimization of delivery activities and by 7% compared to the third variant (Construction of a distribution center in the Delta area). The obtained solution for the optimization of delivery activities points out that the construction of a distribution center near the city center constitutes a financially more reasonable solution due to the approximate distance between the two stakeholder groups. However, the construction of a distribution center in the proposed location, besides satisfying the basic criterion for minimizing the total cost of delivery, also satisfies a much wider defined criterion for the application of smaller vehicles. The possibility of using smaller transport vehicles is possible primarily due to the immediate proximity of the origin and the predicted destinations in the city center. The application of smaller vehicles would result in the grouping of consignments and greater utilization of the capacity of transport vehicles. The construction and integration of the distribution center (Sušak) in the supply chain can be achieved and significantly reduces the congestion in the city center and the number of illegal and inadequate delivery points, limiting the normal vehicle traffic flow, but also achieving long-term objectives in terms of reducing the greenhouse gas concentrations that HDV vehicles cause by their structure. The fulfillment of the mentioned objectives can only be achieved by adequate aspiration in defining measures and reconstructing the components of the delivery system, considering the concept of sustainability of urban centers.

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