DRAFT MODEL OF DELIVERY ROUTES AT A CITY LOGISTICS SCALE WHEN APPLYING THE CLARKE-WRIGHT METHOD

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Abstract

The manuscript deals with the subject of determining the optimal delivery routes in terms of supplying urban distribution centers when minimizing the distance traveled in a particular region for the purpose of addressing city logistics issues using the specific Operations Research method, namely the Clarke-Wright method. Thus, the main paper objective is to examine the issue: what are the optimal transport journeys from the specific object among individual customers in a certain region in order to execute minimum transport performance? First two sections of the manuscript specify the relevant concepts regarding the issue of distribution tasks and vehicle routing problem, and presents data and methods in relation to this research study. The most significant part of the article models the individual routes to determine the optimal interconnections of urban distribution center and their supply from one logistics service center in a regional logistics network at a city logistics scale when applying the Clarke-Wright method. The last sections of the elaborated research study evaluate the major findings and discuss the possible future initiatives in the topic addressed.

Keywords: city logistics, Vehicle Routing Problem, Operations Research, urban distribution center, Clarke-Wright method

1. Introduction

The distribution of goods at a city logistics scale in a specific city agglomeration in the form of circuit routes; i.e. deliveries for which it is possible to use specific mathematical methods intended to address such tasks, are usually addressed by specific vehicle routing problem techniques. All the deliveries need to be described, including the original distribution model. All the parameters, prerequisites and requirements, which need to be taken into account when modeling certain deliveries, also must be specified. If required by the given method, this includes, but is not limited to, defining the optimization criterion and restrictive conditions necessary to plan delivery routes applying selected mathematical methods [14].

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Practical using the selected methods of Operations Research when modeling circuit deliveries is generally demonstrated on a particular model example of material distribution within certain transport territory starting from the point of origin. Such techniques to be applied include, e.g. [25, 26]:

- Greedy algorithm;
- Clarke-Wright method;
- Mayer method;
- Nearest Neighbor algorithm.

Greedy algorithm sometimes fails to find the overall optimal solution, since it does not take into consideration all the data, whereby the selection performed by a greedy algorithm may depend on choices being made so far. On the other side, the significant distance or time savings can be achieved even at a city logistics scale after all [2].

Nearest Neighbor algorithm is suitable within types of tasks where only one supplier collects or delivers products to predetermined locations even within an urban territory. Nonetheless, it is not our case [14].

The particular routing paths may be defined even using the **Mayer method**; however, while not providing a comprehensive solution to the distribution task of determining the minimum distance traveled during the delivery. To this end, it is necessary to supplement it with another method utilized to address a single-circuit distribution task. Only after its application, the optimal order of individual operated sites within a single circuit route is identified [17].

Since the manuscript objective is to select a method that allows for dividing the total delivery route, when delivering to multiple nodes from one particular site, into several partial routes, **Clarke-Wright method**, which is a multi-circuit capacity limited vehicle routing problem, appears to be very effective tool to achieve optimal solution [7].

The following parameters are usually investigated for all the methods used [6]:

- values of restrictive conditions (if any) and their compliance;
- transport performance;
- utilization of vehicles' capacity (if determined).

The transport performance generally represents the fundamental monitored attribute. In this research study, an optimization criterion, based on which model delivery routes of cargo in an urban area will be designed by using the Clarke-Wright method, will be considered. In that context, the goal will be to design such routes that minimize this optimization criterion. The transport performance was chosen as an optimization criterion, on the one hand, because its value is directly related to shipping cost and, on the other hand, because it ensures the optimal utilization of the vehicles' used capacity [16]. Based on this value, it will be possible to assess the efficiency of the delivery route designs when using individual methods.

Vehicle capacity utilization will be monitored as well, as it is another important attribute to be taken into account when applying the tool for addressing distribution tasks within city logistics [21, 22].

After designing individual delivery routes of the model example by implementing the particular Operations Research method, the selected resulting designs; i.e. the values of investigated parameters, are usually compared with the original delivery model and with each other [1, 3].

2. Data and material

This section characterizes all the data and methods essential for the purpose of subsequent modeling delivery routes from the given logistics center to customers (urban distribution centers), focusing exclusively at the territory of Žilina within city logistics activities.

In our case, the point of origin is represented by the regional public logistics service center (hereinafter as V_0) is located in the Žilina region (Slovak Republic). This object is proposed to be placed in such a location where high-quality road infrastructure is built, the intensity of trucks is the highest, and also where the location for placing industrial plants outside the central area of the city territory is the best. The design for the V_0 location is based on real options of performing a construction, or possibly repairs of old and ruined industrial buildings (so called brownfields) at particular locations. The location of P. O. Hviezdoslav Street, Žilina perfectly meets those conditions.

From this place, individual urban distribution centers (hereinafter as V_i), as customers, are regularly supplied by particular shipments (material; cargo) using low-capacity vehicle suitable for city logistics deliveries. According to the vehicle routing problem general procedure, the V_0, as a supplier, must ensure the delivery of goods to selected customers (individual V_i in our case), located in specific industrial locations in the city of Žilina (V_1, V_2, ..., V_n), which are sequentially supplied one by one [10]. All these customers, as well as the central point (the origin node) V_0, and individual distances traveled among them in km are vividly sorted in the input distance matrix D (see Table 1).

Tab. 1. Input distance matrix D (distances traveled among centers in km). Source: Author

i/j	V_0	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}
V_0	0	1.2	1.1	2.3	3.6	1.0	3.2	1.8	5.9	2.2	4.7	1.6	1.0	3.4	3.3	2.9	5.3
V_1	1.2	0	1.3	1.0	3.3	1.8	2.0	1.0	3.2	1.3	3.5	0.65	2.1	3.1	2.0	1.7	4.1
V_2	1.1	1.3	0	2.0	4.7	0.45	3.0	2.3	4.2	2.6	4.5	1.6	2.3	4.4	3.0	0.35	4.6
V_3	2.3	1.0	2.0	0	3.3	2.5	1.3	1.1	2.5	1.4	2.8	0.8	2.2	3.2	1.3	2.4	4.7
V_4	3.6	3.3	4.7	3.3	0	3.1	3.2	0.7	3.2	0.45	3.1	1.4	1.9	1.5	3.2	3.3	5.7
V_5	1.0	1.8	0.45	2.5	3.1	0	3.4	2.4	4.6	2.8	4.9	2.1	2.7	5.0	3.4	3.5	5.1
V_6	3.2	2.0	3.0	1.3	3.2	3.4	0	2.0	1.4	2.3	1.6	1.8	3.1	3.9	0.08	3.3	3.8
V_7	1.8	1.0	2.3	1.1	0.7	2.4	2.0	0	3.5	0.35	3.5	0.75	1.2	2.1	2.4	2.6	5.1
V_8	5.9	3.2	4.2	2.5	3.2	4.6	1.4	3.5	0	4.0	0.45	3.0	4.5	3.7	1.4	4.7	5.0
V_9	2.2	1.3	2.6	1.4	0.45	2.8	2.3	0.35	4.0	0	3.2	1.1	1.6	1.8	3.3	3.0	5.8
V_{10}	4.7	3.5	4.5	2.8	3.1	4.9	1.6	3.5	0.45	3.2	0	3.3	4.3	3.6	1.7	4.9	5.3
V_{11}	1.6	0.65	1.6	0.8	1.4	2.1	1.8	0.75	3.0	1.1	3.3	0	2.0	2.9	2.0	2.2	4.7
V_{12}	1.0	2.1	2.3	2.2	1.9	2.7	3.1	1.2	4.5	1.6	4.3	2.0	0	2.9	3.6	3.3	5.7
V_{13}	3.4	3.1	4.4	3.2	1.5	5.0	3.9	2.1	3.7	1.8	3.6	2.9	2.9	0	4.0	4.7	7.7
V_{14}	3.3	2.0	3.0	1.3	3.2	3.4	0.08	2.4	1.4	3.3	1.7	2.0	3.6	4.0	0	3.4	3.8
V_{15}	2.9	1.7	0.35	2.4	3.3	3.5	3.3	2.6	4.7	3.0	4.9	2.2	3.3	4.7	3.4	0	4.9
V_{16}	5.3	4.1	4.6	4.7	5.7	5.1	3.8	5.1	5.0	5.8	5.3	4.7	5.7	7.7	3.8	4.9	0

In regard to comply with individual city logistics aspects, prerequisites; i.e. input data and restrictive conditions of this assignment, consist in [2, 15]:

- deliveries are carried out in the form of circuit journeys, and thereby it is all about vehicle routing problem with capacity limitations;
- a total of 3 freight supply vehicles are available for deliveries ($A - C$; basic parameters of all the vehicles in operation are shown in the following Table 2):
  - the capacity limitation of vehicles (given by the payload of vehicles in use) represents the main restrictive condition of the addressed distribution task;
  - the temporal limitation of deliveries is in this case given by the maximum continuous driving time of the driver – it is stipulated by the Regulation (EC) No. 561/2006 of the European Parliament and of the Council at 4.5 hours (240 min) per drive (in our case, including times of ancillary works and all the loading / unloading times) [11];
- the optimization criterion is represented by the total transport performance of vehicles used for delivery routes (in km traveled), which is directly related to shipping cost for deliveries and is also partially associated with the optimal utilization of the vehicle total capacity;
- for each urban distribution center, sizes of individual required shipments are pre-determined;
- constant average vehicle speed of 40 kmh^{-1} is specified;

- relatively flat roads' height profile in the city of Žilina is maintained;
- night delivery of goods to customers is preferred, and thereby no additional waiting occurs, since the light-signal device at intersections is switched off.

Tab. 2. Basic data on used vehicles. Source: Author

Parameter	Vehicle		
	A	B	C
Vehicle category	N2	N2	N2
Fuel consumption	17 l/100 km	14 l/100 km	16 l/100 km
Payload	**3,400 kg**	**2,500 kg**	**3,000 kg**
Length of loading space	4,900 mm	4,060 mm	4,530 mm
Width of loading space	2,230 mm	1,970 mm	2,060 mm
Height of loading space	2,400 mm	2,100 mm	2,290 mm

As for cargo delivery to customers for the original state, one particular delivery day was selected to serve as an example. At this example, the design of optimized delivery routes will be outlined in the manuscript section 3 using the Clarke-Wright method for addressing vehicle routing problem, and the possibility of its implementation for the proposal of daily circuit routes will be analyzed.

In addition to the distance matrix D (see Table 1), it is also necessary to create a time matrix that expresses the travel time among individual nodes of the model example [7]. This matrix is going to be used to calculate the total daily travel time of drivers for delivery routes using the Clarke-Wright method (the total travel time includes the overall time spent by delivering the consignments to customers, including the time of unloading the goods at each customer – 15 minutes, and also the time required for all the operations in the logistics center V_0 – 1 hour). As for the distance matrix, *route-planner mapa.cz* was used to construct this matrix to determine the travel time among nodes in minutes. This matrix was also based on the constant average vehicle speed when delivering (40 kmh^{-1}). The input time matrix is again of 17×17 type (see the following Table 3).

Tab. 3. Input time matrix (travel time among individual centers in min). Source: Author

i/j	V_0	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}
V_0	0	2.5	2.0	4.5	7.5	2.0	6.5	4.0	12.0	4.5	9.5	3.0	2.0	7.0	6.5	6.0	11.0
V_1	2.5	0	3.0	2.0	7.0	14.0	4.5	2.0	6.5	2.5	7.0	1.5	4.0	6.0	4.5	3.5	8.5
V_2	2.0	3.0	0	4.0	9.5	1.0	6.0	5.0	8.5	5.5	9.0	3.0	5.0	9.0	6.0	1.0	9.5
V_3	4.5	2.0	4.0	0	7.0	5.0	3.0	2.5	5.0	3.0	6.0	2.0	4.5	6.5	2.5	5.0	9.5
V_4	7.5	7.0	9.5	7.0	0	6.0	6.5	1.5	6.5	1.0	6.5	3.0	4.0	3.0	6.5	6.5	11.5
V_5	2.0	4.0	1.0	5.0	6.0	0	7.0	5.0	9.0	5.5	10.0	4.5	5.5	10.0	7.0	7.0	10.0
V_6	6.5	4.5	6.0	3.0	6.5	7.0	0	4.0	3.0	4.5	3.0	4.0	6.0	8.0	1.0	6.5	8.0
V_7	4.0	2.0	5.0	2.5	1.5	5.0	4.0	0	7.0	1.0	7.0	1.5	2.5	4.5	5.0	5.5	10.5
V_8	12.0	6.5	8.5	5.0	6.5	9.0	3.0	7.0	0	8.0	1.0	6.0	9.0	6.5	3.0	9.5	10.0
V_9	4.5	2.5	5.5	3.0	1.0	5.5	4.5	1.0	8.0	0	6.5	2.0	3.0	4.0	6.5	6.0	12.0
V_{10}	9.5	7.0	9.0	6.0	6.5	10.0	3.0	7.0	1.0	6.5	0	6.5	8.5	7.0	3.5	10.0	10.5
V_{11}	3.0	1.5	3.0	2.0	3.0	4.5	4.0	1.5	6.0	2.0	6.5	0	4.0	6.0	4.0	4.5	9.5
V_{12}	2.0	4.0	5.0	4.5	4.0	5.5	6.0	2.5	9.0	3.0	8.5	4.0	0	6.0	7.0	6.5	10.5
V_{13}	7.0	6.0	9.0	6.5	3.0	10.0	8.0	4.5	6.5	4.0	7.0	6.0	6.0	0	8.0	9.5	15.5
V_{14}	6.5	4.5	6.0	2.5	6.5	7.0	1.0	5.0	3.0	6.5	3.5	4.0	7.0	8.0	0	7.0	7.5
V_{15}	6.0	3.5	1.0	5.0	6.5	7.0	6.5	5.5	9.5	6.0	10.0	4.5	6.5	9.5	7.0	0	10.0
V_{16}	11.0	8.5	9.5	9.5	11.5	10.0	8.0	10.5	10.0	12.0	10.5	9.5	10.5	15.5	7.5	10.0	0

In the following Tables 4-6, the original delivery route attributes, for which vehicles A, B and C were selected, are summarized. These tables include the order of each node (customer) supply, the total distance traveled of the circuit route and the distance between corresponding nodes, customer demand for goods, driving time between corresponding nodes and unloading time at each node.

Tab. 4. Original delivery route attributes for vehicle A. Source: Author

Route	Distance traveled (km)	Customer demand (kg)	Driving time (min)	Unloading time (min)
V_0	-	-	-	-
V_1	1.2	160 kg	2.5	15
V_2	1.3	600 kg	3.0	15
V_3	2.0	180 kg	4.0	15
V_4	3.3	100 kg	7.0	15
V_5	3.1	140 kg	6.0	15
V_7	2.4	200 kg	5.0	15
V_6	2.0	360 kg	4.0	15
V_8	1.4	100 kg	3.0	15
V_9	4.0	360 kg	8.0	15
V_0	2.2	-	4.5	-
Total	26	2,200	53	135

Tab. 5. Original delivery route attributes for vehicle B. Source: Author

Route	Distance traveled (km)	Customer demand (kg)	Driving time (min)	Unloading time (min)
V_0	-	-	-	-
V_{12}	1.0	840	2.0	15
V_{10}	4.3	360	8.5	15
V_{11}	3.3	840	6.5	15
V_0	1.6	-	3.0	-
Total	10.2	2,040	20	45

Tab. 6. Original delivery route attributes for vehicle C. Source: Author

Route	Distance traveled (km)	Customer demand (kg)	Driving time (min)	Unloading time (min)
V_0	-	-	-	-
V_{15}	2.9	120	6.0	15
V_{14}	3.4	400	7.0	15
V_{16}	3.8	700	7.5	15
V_{13}	7.7	140	15.5	15
V_0	3.4	-	7.0	-
Total	21.2	1,360	43	60

On the basis of the data obtained (in Tables 4-6 above), it can be stated that all the original delivery models meet each of the restrictive conditions.

3. Results – designed model of optimized cargo delivery to customers using the Clarke-Wright method

In this paper section, particular delivery routes for the model example are designed using the Clarke-Wright method. This is done according to individual steps for addressing the Clarke-Wright method; see numerous literatures, e.g. [5, 9, 12]. The first two steps are intended to construct a distance matrix D (see Table 1). For that reason, we can go directly to the next step to create an initial solution of the task. This means to create elementary routes from the origin point (V_0) to individual nodes (V_i) and back. For individual elementary routes, it is also important to specify the parameter values related to the optimization criterion as well as restrictive conditions of the assignment addressed. This will allow for examining the optimization criterion value, and whether individual routes meet these conditions. The model elementary routes with their corresponding parameters are listed in Table 7. Attributes indicated in the table are as follows [19]:

- l – total distance of the route (km);
- q_i – amount of the customer demand (kg);
- t_{ij} – driver driving time (min);

- t_v – unloading time at individual customers (min);
- t_c – total travel time of drivers (min).

Tab. 7. The model elementary routes with their parameters. Source: Author

Routes	l (km)	q_i (kg)	t_{ij} (min)	t_v (min)	t_c (min)
$V_0 - V_1 - V_0$	2.4	160	5	15	80
$V_0 - V_2 - V_0$	2.2	600	4	15	79
$V_0 - V_3 - V_0$	4.6	180	9	15	84
$V_0 - V_4 - V_0$	7.2	100	15	15	90
$V_0 - V_5 - V_0$	2.0	140	4	15	79
$V_0 - V_6 - V_0$	6.4	360	13	15	88
$V_0 - V_7 - V_0$	3.6	200	8	15	83
$V_0 - V_8 - V_0$	11.8	100	24	15	99
$V_0 - V_9 - V_0$	4.4	360	9	15	84
$V_0 - V_{10} - V_0$	9.4	360	19	15	94
$V_0 - V_{11} - V_0$	3.2	840	6	15	81
$V_0 - V_{12} - V_0$	2.0	840	4	15	79
$V_0 - V_{13} - V_0$	6.8	140	14	15	89
$V_0 - V_{14} - V_0$	6.6	400	13	15	88
$V_0 - V_{15} - V_0$	5.8	120	12	15	87
$V_0 - V_{16} - V_0$	10.6	700	22	15	97

After compiling the elementary routes, the next step of the Clarke-Wright method is to create a matrix of preferential coefficients $Z = \{z_{ij}\}$ according to the equation $z_{ij} = (d_{0i} + d_{0j} - d_{ij})$, which expresses the divide between the sum of distances of two elementary routes and the route distance created by their merging (see Table 8) [24].

Tab. 8. Matrix of preferential coefficients Z. Source: Author

i/j	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}
V_1	0	1.0	2.5	1.5	0.4	2.4	2.0	3.9	2.1	2.4	2.15	0.1	1.5	2.5	2.4	2.4
V_2		0	1.4	0.0	1.65	1.3	0.6	2.8	0.7	1.3	1.1	-0.2	0.1	0.4	3.65	1.8
V_3			0	2.6	0.8	4.2	3.0	5.7	3.1	4.2	3.1	1.1	2.5	4.3	2.8	2.9
V_4				0	1.5	3.6	4.7	6.3	5.35	5.2	3.8	2.7	5.5	3.7	3.2	3.2
V_5					0	0.8	0.4	2.3	0.4	0.8	0.5	-0.7	-0.6	0.9	0.4	1.2
V_6						0	3.0	7.7	3.1	6.3	3.0	1.1	2.7	6.42	2.8	4.7
V_7							0	4.2	3.65	3.0	2.65	1.6	3.1	2.7	2.1	2.0
V_8								0	4.1	10.15	4.5	2.4	5.6	7.8	4.1	6.2
V_9									0	3.7	2.7	1.6	3.8	2.2	2.1	1.7
V_{10}										0	3.0	1.4	4.5	6.3	2.7	4.7
V_{11}											0	0.6	2.1	2.9	2.3	2.2
V_{12}												0	1.5	0.7	0.6	0.6
V_{13}													0	2.7	1.6	1.0
V_{14}														0	2.8	4.8
V_{15}															0	3.3
V_{16}																0

After creating this matrix, it is possible to proceed to the very design of circuit routes. This will take place in a form of iterations, where the elementary routes will be gradually merged (grouped) based on preferential coefficient values given in the matrix Z. In individual iterations, the admissibility of merging routes will also be checked; i.e. whether the merged route meets all the restrictive conditions, or whether the merging does not group two marginal nodes of one route. Thus, the first step of this assignment is to seek the highest coefficient value in the Z matrix. Value of 10.15 represents such a coefficient which connects the vertices of V_8 and V_{10}. Therefore, in the first iteration, we will investigate an option to interconnect these nodes [4, 17].

Due to the significant extent of iterations executed, only the first one, 21st and the last one (23rd) are shown in this manuscript, see as follows:

Iteration 1

Maximum value: $Z_{ij} = Z_{8,10} = 10.15$

Original route: $V_0 - V_8 - V_0$ *and* $V_0 - V_{10} - V_0$

Merged route: $V_0 - V_8 - V_{10} - V_0$

Merged route distance: 11.05 km

Unloading time: 30 min

Total travel time: 22.5 + 30 + 60 = 112.5 min < 4.5 h (270 min)

$q_i = 460\ kg < 3{,}400\ kg;\ q_i = 460\ kg < 2{,}500\ kg;\ q_i = 460\ kg < 3{,}000\ kg$

Merging these delivery routes can be done, as this is in compliance with all the restrictive conditions.

Iteration 21

Maximum value: $Z_{ij} = Z2,5 = 1.65$

Original route: $V_0 - V_1 - V_3 - V_6 - V_8 - V_{10} - V_{14} - V_{16} - V_{15} - V_2 - V_0$ *and* $V_0 - V_5 - V_0$

Merged route: $V_0 - V_1 - V_3 - V_6 - V_8 - V_{10} - V_{14} - V_{16} - V_{15} - V_2 - V_5 - V_0$

Merged route distance: 17.55 km

Unloading time: 150 min

Total travel time: $36.5 + 150 + 60 = 246.5$ *min* < 4.5 *h (270 min)*

$q_i = 3{,}120$ *kg* $< 3{,}400$ *kg;* $q_i = 3{,}120$ *kg* $> 2{,}500$ *kg;* $q_i = 3{,}120$ *kg* $> 3{,}000$ *kg*

These routes can be merged, but only if vehicle A is deployed. Remaining two vehicles do not dispose of sufficient capacity to be used for such a route. By merging routes, the node V_2 *ceases to be the extreme node of the route; and thus, the preferential coefficients related to these nodes should be omitted from the subsequent steps of the task.*

Iteration 23

Maximum value: $Z_{ij} = Z12,13 = 1.5$

Original route: $V_0 - V_{12} - V_0$ *and* $V_0 - V_{11} - V_7 - V_9 - V_4 - V_{13} - V_0$

Merged route: $V_0 - V_{11} - V_7 - V_9 - V_4 - V_{13} - V_{12} - V_0$

Merged route distance: 8.55 km

Unloading time: 90 min

Total travel time: $17.5 + 90 + 60 = 167.5$ *min* < 4.5 *h (270 min)*

$q_i = 2{,}480$ *kg* $< 3{,}400$ *kg;* $q_i = 2{,}480$ *kg* $< 2{,}500$ *kg;* $q_i = 2{,}480$ *kg* $< 3{,}000$ *kg*

Merging these delivery routes can be done, as this is in compliance with all the restrictive conditions. Nevertheless, by merging these routes, the node V_{13} *has ceased to be the extreme node of the route.*

Thus, using the Clarke-Wright method, two delivery routes in total have been designed to supply all the customers (urban distribution centers). To operate one route, it is necessary to use vehicle A due to the cargo weight to be transported and vehicle capacity, and for the second route, it is desirable to deploy a supply vehicle *B*, where the maximum payload capacity would be used more efficiently [13, 23].

In the following Table 9, the values related to the design of circuit delivery routes for both vehicles are clearly summarized using the Clarke-Wright method.

Tab. 9. Design of delivery routes for both vehicles. Source: Author

Routes	Vehicle	l (km)	q (kg)	t_{ij} (min)	t_v (min)	t_c (min)
$V_0 - V_1 - V_3 - V_6 - V_8 - V_{10} - V_{14} - V_{16} - V_{15} - V_2 - V_5 - V_0$	A	17.55	3,120	36.5	150	246.5
$V_0 - V_{11} - V_7 - V_9 - V_4 - V_{13} - V_{12} - V_0$	B	8.55	2,480	17.5	90	167.5

The overview above involves individual values of pre-determined attributes regarding the application of the Clarke-Wright method; namely the order of visits (delivery sequences) of each node, specifying the appropriate vehicle for the given route, the total distance traveled l (km), the total weight of customers' demands q (kg), the total driving time of drivers t_{ij} (min), the total unloading time t_v (min) and the total travel time of drivers t_c (min) [8].

4. Discussion of the results

Following the conducted analysis of all the delivery routes, it is now reasonable to evaluate them by the individual vehicles both for original state as well as for the proposed model (optimized by the Clarke-Wright method) [18, 20]. Tables 10 and 11 summarize all the data relevant to this evaluation (separately for original and designed delivery routes).

Tab. 10. Evaluation of all the original delivery routes carried out. Source: Author

Optimization criterion value	57.4 km
Number of delivery routes	3
Number of vehicles used	3
Capacity utilization of vehicle *A*	64.71%
Capacity utilization of vehicle *B*	81.60%
Capacity utilization of vehicle *C*	45.33%
Average capacity utilization of vehicles	63.88%

From Table 10, it is evident that the original model within the distribution routes achieved the optimization criterion value of 57.4 km, a total of 3 vehicles were used, and for each of them, a specific delivery route was assigned, with an average capacity of all the vehicles being used of 63.88%.

Tab. 11. Evaluation of the designed delivery routes using the Clarke-Wright method. Source: Author

Optimization criterion value	26.1 km
Number of delivery routes	2
Number of vehicles used	2
Capacity utilization of vehicle *A*	91.76%
Capacity utilization of vehicle *B*	99.20%
Capacity utilization of vehicle *C*	-
Average capacity utilization of vehicles	95.48%

In Table 11, it can be noticed that, by designing the delivery routes when using the Clarke-Wright method, an optimization criterion of 26.1 km is calculated, which is a considerably lower value compared to the original delivery routes (specifically 57.4 km). As previously stated, a total of two vehicles (A and B) need to be deployed, while one particular route is assigned to each of them. Table 11 also states that the capacity of vehicle A is utilized at 91.76% and the payload of vehicle B would be utilized at 99.20%. On average, the capacity of both deployed vehicles is used at 95.48%, which also represents a significantly higher value compared to the original method of distribution routes (specifically 63.88%).

5. Conclusion

Following the above results, it can be stated that to determine the optimal delivery routes in terms of supplying individual urban distribution centers when minimizing distance traveled in a particular region for the purpose of addressing city logistics issues, the specific methods of vehicle routing problem may be implemented.

Previous sections of the manuscript dealt with the distribution task (vehicle routing problem) at a city logistics scale (in particular, the city of Žilina) in the form of circuit delivery routes, for which the specific mathematical (Operations Research) method was used. The delivery example was adequately described, including the original supply model. All the parameters, prerequisites and requirements, taken into consideration during the modeling process, were specified as well. This included defining the optimization criterion and characterizing the restrictive conditions necessary to execute the model delivery routes using particular mathematical method.

Application of the Clarke-Wright method when modeling itself was demonstrated on a specific model example of cargo distribution at a city logistics scale, wherein it started from the national public logistics service center located in the P. O. Hviezdoslav Street, Žilina, Slovak Republic. Moreover, individual attributes were examined for the applied method as follows: values of restrictive conditions and their compliance; transport performance and utilization of vehicles' capacity.

The transport performance (the total distance traveled), being the primary verified parameter, was considered to be an optimization criterion, based on which individual delivery routes in an urban area were designed and optimized using particular mathematical apparatus. From this view, the objective of this research study was to design and model such delivery routes that minimize the total distance traveled by deployed vehicles. In line with this value, it was easy to evaluate and compare the final efficiency level of the design achieved by implementing the method.

Capacity utilization of individual vehicles deployed was compared as well, as it is another important aspect to be considered when addressing vehicle routing problem at a city logistics scale.

In addition to the previously mentioned, these types of tasks and problems may be successfully transferred to similar smaller or extensive assignments, and should be examined more comprehensively in the future; hence, for example, future research studies can be focused in particular on topics as follows:

- Distribution system at a scale of city logistics, designed on the basis of intermodal transport, preserves space for business activities for all current carriers and logistics providers and is able to bring them certain benefits. Such a system may, therefore, be funded from public budgets without distorting the market environment.
- The implementation of an effective information system (telematics applications) should also be one of the other recommendations in the field of designing a network of logistics objects and subsequent optimal distribution routes. Telematics and information technologies are important both when providing logistics services and when managing transport processes, and their interconnection with the surroundings.

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