HOUSEHOLDS IN THE FUNCTION OF COLLECTION AND DELIVERY POINTS: LOCATION DECISION PROBLEM

Snežana Tadić[a,*], Mladen Krstić[a], Miloš Veljović[a], Slobodan Zečević[a]

[a] University of Belgrade, Faculty of Transport and Traffic Engineering, Logistics Department, Serbia

Abstract: *One of the home delivery models that have become increasingly important in recent decades is delivery to the collection and delivery point (CDP). This can be a commercial facility with staff (trade, catering, service facilities) or without staff (automated packing stations, parcel lockers). This paper discusses the idea that the role of CDPs is performed by households of customers, in order to reduce flows, distance traveled, costs and other negative effects, and presents the procedure of household selection, i.e. locating CDPs using the median location problem. The problem was solved on a hypothetical example for the City of Belgrade. Two strategies have been defined, locating the median in each zone of the service area and locating one median for the entire service area. The location of one median was done in two ways. In the first case, real distances between potential locations were used, medians in each zone were used as potential locations for CDPs, a linear programming task was defined, and a solution was obtained using a solver. In the second case, Euclidean distances and an algorithm for determining a single median were used. In both cases, the same solution was obtained.*

Keywords*: home delivery, collection and delivery point, household, location problem, median.*

1. INTRODUCTION

In recent decades, under the influence of Internet ordering and e-commerce, the home delivery service, i.e. delivery of goods to customers, has been intensively developed. This segment of the supply chain is often called last mile delivery. Given the territorial dispersion of customers, complex requirements in terms of delivery time, small orders, high percentage of unsuccessful deliveries and return flows, the last mile is the most inefficient and expensive part of the supply chain (Gevaers et al., 2009). In addition,

* s.tadic@sf.bg.ac.rs

deliveries can lead to an increase in freight transport and the accompanying negative effects (congestion, emissions, noise, etc.).

In order to overcome these challenges and (or) improve the level of service, different models of home delivery are being developed from the aspect of (Tadić & Veljović, 2021): need for ordering, frequency, ordering and payment system, starting and end point, executors, reception method, security, delivery area, speed and time of realization, characteristics of return flows, applied technology, etc. The classification of the delivery models from the aspect of the end point is especially interesting. Although the name of the service indicates that the goods are most often delivered to the home address, many authors (Visser et al., 2014; Punakivi, 2003; Browne et al., 2001) under the term "home delivery" include deliveries to other locations at the customer's request, such as (Tadić & Veljović, 2021): household of neighbors, friends, relatives, customer's place of work, collection and delivery points, drop-off company, trunk of the customer's car (in this case the location is variable), etc. These locations are used as a targeted (first) or alternative delivery destination (after a failed home delivery).

Collection and delivery point (CDP) is one of the most commonly used solutions for delivering goods to customers. Selecting appropriate facilities and locating CDPs is a very important task and strategic decision for their efficiency (Morganti et al., 2014a), given that the selected location should reduce flows and costs, for the benefit of all stakeholders. Purpose-built or existing facilities with staff (e.g. post offices, shops, restaurants, etc.) or without staff (automated packing stations, parcel lockers) are used as CDPs. On the other hand, the role of CDPs can be played by the customers themselves, i.e. their households (Tadić et al., 2022). Locating CDPs can be done using different location models, e.g. center, median, coverage, etc. Mislocation can lead to overloading of some CDPs and underutilization of others.

Numerous authors have dealt with the concept of CDPs in recent years. Morganti et al. (2014b) analyzed the application of attended and unattended CDPs in Germany and France. Weltevreden (2008) investigated how customers in the Netherlands accept CDPs and what are the effects of their application from the aspect of mobility, as well as the business of trading companies. Zenezini et al. (2018) analyzed the possibilities and obstacles for more mass application of CDPs from the perspective of courier, express and parcel services. Song et al. (2009) investigated the effects of the introduction of various CDPs (post offices, railway stations, retail stores) as alternative destinations after unsuccessful deliveries on the distance traveled, harmful emissions and transport costs and found that their use can bring significant benefits compared to traditional delivery. Wu et al. (2015) used public transport data and historical delivery data to locate unattended CDPs, estimating patterns of population mobility. Wang et al. (2017) developed a location covering model in order to define the optimal network of CDPs so that the scope of covered demand is maximized. Lin et al. (2020a; 2020b) addressed the problem of CDP location and developed a multinomial logit model and Threshold Luce model to assess customer choice in using CDP services.

This paper will present the procedure for selecting a household as a location for CDP in the part of the City of Belgrade, using the p-median location problem, which is the main goal and contribution of the paper. Two strategies will be defined: locating the median in each zone of the service area and locating one median for the entire service area. Locating one median will be done in two ways: as a task of linear programming and with algorithm for determining one median. The paper is organized as follows. After the introduction, the second section describes the concept of CDP. In the third section, the CDP(s) is located in the service area. Finally, concluding remarks and directions of future research are given.

2. COLLECTION AND DELIVERY POINTS

CDPs are a network of locations where suppliers/operators pick up and deliver ordered goods, and customers or consignees pay, collect or return goods (Yuen et al., 2018; Piplani & Sarasvat, 2012). These places are also called: collection points, cluster points, pick-up points, pick-own-parcel points, reception points, etc. (Tadić & Veljović, 2021). There are two variants of CDP, attended (with staff) and unattended (without staff). In the first case, the persons employed in the CDP receive and hand over the goods to the customers, while in the second case the customers pick up the goods themselves, most often from lockers or containers, using the order reference code.

There are numerous advantages of applying CDPs for all stakeholders (Tadić & Veljović, 2021): delivery organizers (minimized number of failed deliveries, enabled consolidation of goods, reduced mileage, number of employees and vehicles, number of vehicle starts, energy consumption, etc.), customers (eliminated need to wait for delivery at home, lower delivery costs, the delivery of goods from the CDP to the home address is most often performed by customers during everyday business trips, shopping, etc., so there are no additional costs, etc.), community and environment (reduced number of flows and thus congestion, demand for parking in residential areas, emissions, customers often deliver from CDP to their home address on foot or by bicycle, which has positive social, health and environmental effects, etc.).

3. LOCATING CDP USING P-MEDIAN LOCATION PROBLEM

As already mentioned, the selection of appropriate facilities and the location of CDPs are strategic decisions for their efficiency, and the wrong location can lead to overloading or underutilization of CDPs. Therefore, locating should be done in accordance with many factors, especially population density, i.e. the density of customers/requests. Accordingly, more CDPs are located in densely populated, urban areas than in rural ones, so their location is closer to the customers. Thus, in some parts of France, the population is 1.6 km from the nearest CDP in urban areas and 6 km in rural areas, which makes customers in rural areas largely dependent on cars (Morganti et al., 2014a). There are also differences in the choice of object type for CDP. In urban areas, CDPs near traffic hubs are most often used as CDPs, while due to the small number of such facilities, unattended CDPs (automated packing stations, parcel locker) are more often located in rural areas (Hübner et al., 2016). The exceptions are post offices, which also often serve as CDPs in rural areas (Browne et al., 2001). Households are a suitable facility for CDPs, both in urban and rural areas for a number of reasons. They are present in both urban and rural areas. There is no need to build additional infrastructure, which requires investment and space, which is particularly congested and expensive in urban areas. Finally, this may be a chance to use the underutilized capacity of households, as well as employment and additional earnings for its members. An informal form of this practice has existed for a long time. For example, there are examples of one tenant receiving and temporarily storing goods for multiple customers from a residential building or a particular neighborhood, or one resident receiving and temporarily storing goods for multiple customers from a rural settlement.

In this paper, the location problem of p-median was used to solve the problem of locating CDP, and its applicability was tested on a hypothetical example for a company in the City of Belgrade. The hypothetical company delivers the goods to the home address of the permanent customers located in 7 zones (Figure 1). The company plans to introduce a new delivery model - delivery to CDP, in order to reduce flows, the number of employees and vehicles, energy consumption and costs, as well as to attract customers with a service that is cheaper than home delivery. The company wants to use the households of its customers as CDPs, with appropriate monetary or other compensation (e.g. reduced price of goods, free delivery, etc.), in order to avoid the cost of investing in CDPs. The company is considering two strategies, the introduction of one CDP for each zone and the introduction of one CDP for the entire service area.

Figure 1. Service zones and locations of customers

CDP was located using the p-median (p = 1) location problem. This problem was first formulated by Hakimi (1964). It involves locating a predetermined number of objects on the network, so as to minimize the average distance, travel time or transport costs from the object to the customer or vice versa. This problem and its extensions are useful for modeling in many situations, such as locating industrial plants, warehouses, public institutions, etc. (Mladenović et al., 2007), as well as distribution systems (Teodorović, 2016).

First, by applying the p-median location problem (p = 1), the location of the CDP, i.e. one household that can have this role, within each zone was defined, thus defining the first strategy. Thus, the model was applied to each of the 7 zones. Then, in order to define another strategy, using the same location model, one site was selected for the CDP, with potential sites now being pre-selected sites (medians) within each zone.

It is assumed that households, as potential locations for CDP, have adequate access infrastructure (parking, elevator, etc.), storage space and information and communication systems (which enable communication with suppliers and customers) and voluntarily accept the role of CDP. There is at least one person present in the household in the period from 8 am to 8 pm who can receive or hand over the goods to the customer. The model is defined as follows (Teodorović, 2007):

Minimize

$$F = \sum_{i}^{n} \sum_{j}^{n} f_i d_{ij} x_{ij} \tag{1}$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = 1, \qquad i = 1, 2, \dots, n \tag{2}$$

$$\sum_{j=1}^{n} x_{jj} = 1 \tag{3}$$

$$x_{jj} \geq x_{ij}, \qquad i, j = 1, 2, \dots, n; i \neq j \tag{4}$$

$$x_{ij} \in \{0,1\}, \qquad i, j = 1, 2, \dots, n \tag{5}$$

In the case of the first strategy, i.e. the application of the CDP selection model in each zone, the notation has the following meaning:

n – number of customers in the zone

$$x_{ij} = \begin{cases} 1, \text{ if the goods for customer } i \text{ are delivered to user } j \\ 0, \text{ otherwise} \end{cases}$$

d_{ij} – distance from customer *i* to customer *j*

f_i –number of customer requests for delivery in the observed period.

Constraint (2) ensures that each customer is served by the CDP, i.e. in the selected household. Constraint (3) indicates that one CDP should be located in the zone. Constraint (4) indicates that customer whose household is selected for CDP receive their orders in their own household. Constraint (5) reflects the binary nature of the variablex_{ij}. In order to solve the set task, data on the number of deliveries to each customer in each zone during 20 days were simulated, according to the uniform distribution U(0,10). The total number of deliveries during this period is 190. These data, together with the distances$d_{ij}$are shown in Table 1. Using the defined model in the Microsoft Excel solver for each zone, the solutions, i.e. CDP locations, shown in Figure 2, were obtained.

Table 1. Distances d_{ij} from customer *i* to customer *j* (in meters) (values taken from the *Google maps* application service)

zone	zone 1					zone 2					
customer	1	2	3	4	5	customer	1	2	3	4	5
1	0	160	400	450	400	1	0	1500	2400	2600	2600
2	160	0	230	300	220	2	500	0	350	550	600
3	400	230	0	280	190	3	1000	1900	0	190	210
4	450	300	280	0	130	4	1000	1800	1000	0	140
5	400	220	190	130	0	5	850	1600	900	450	0
num. of requests	3	8	10	8	3	num. of requests	8	7	0	7	9

zone	**zone 3**					**zone 4**					
customer	**1**	**2**	**3**	**4**	**5**	**customer**	**1**	**2**	**3**	**4**	**5**
1	0	180	500	350	450	1	0	100	92	2400	3900
2	180	0	300	400	270	2	2200	0	2300	2300	3800
3	400	230	0	350	210	3	2200	9	0	2400	3800
4	550	400	150	0	120	4	1200	1300	1300	0	1600
5	450	270	30	120	0	5	800	900	900	950	0
num. of requests	4	4	7	5	8	**num. of requests**	5	9	2	1	6
zone	**zone 5**					**zone 6**					
customer	**1**	**2**	**3**	**4**	**5**	**customer**	**1**	**2**	**3**	**4**	**5**
1	0	750	350	500	550	1	0	400	300	280	450
2	800	0	500	300	350	2	500	0	600	750	400
3	300	1000	0	750	800	3	650	300	0	450	160
4	600	300	350	0	160	4	850	500	300	0	400
5	450	700	180	500	0	5	800	400	160	550	0
num. of requests	8	2	5	4	7	**num. of requests**	6	3	8	3	5
zone	**zone 7**										
customer	1	2	3	4	5						
1	0	140	280	350	400						
2	750	0	1000	500	700						
3	400	550	0	170	110						
4	250	400	450	0	170						
num. of requests	8	5	6	2	4						

Figure 2. Locations of CDPs in all service zones

An identical model was applied to select the location of one CDP for the entire service area. In this case, the notation used in the model has the following meaning:

n – number of zones,

$$x_{ij} = \begin{cases} 1, \text{ if customers from zone } i \text{ are served in zone } j \\ 0, \text{ otherwise} \end{cases}$$

d_{ij} – the distance from the potential location (median of customers) in zone i to the potential location (median of customers) in zone j,

f_i – number of delivery requests in the zone i in the observed period.

Constraint (2) ensures that customers from each zone are served by the CDP. Constraint (3) provides the selection of one zone in which the CDP will be located. Constraint (4) ensures that goods for customers from the zone in which it is located are also delivered to the CDP. Constraint (5) reflects the binary nature of the variable x_{ij}. Table 2 shows the distances d_{ij} and the number of requests (deliveries) in each zone. By applying the defined model in the solver of Microsoft Excel, the location of the CDP, shown in Figure 3, was obtained.

Table 2. Distances d_{ij} from the potential location in the zone *i* to the potential location in zone *j* (in meters) (values taken from the application service *Google maps*) and the number of requests of zones in the observed period

zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	0	650	400	900	1500	1100	1500
2	1900	0	1700	250	3100	1500	800
3	500	850	0	1100	1700	750	1700
4	1700	2100	1400	0	2900	1200	550
5	1400	1000	1400	1300	0	2200	1900
6	650	1000	400	1300	1800	0	1800
7	2600	2200	2600	2400	2000	2800	0
num. of requests	32	31	28	23	26	25	25

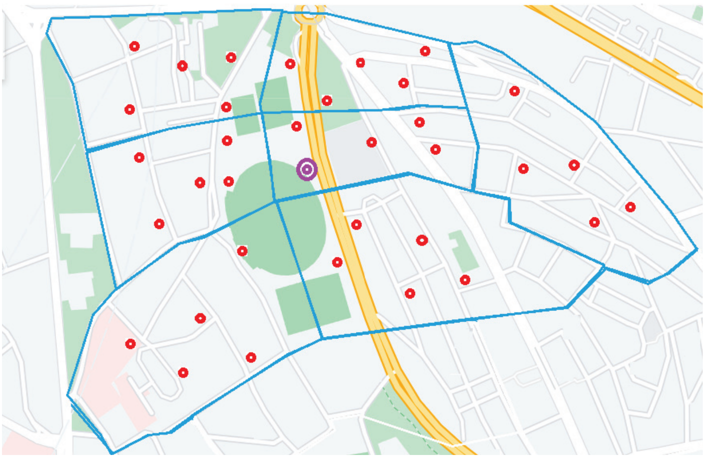

Figure 3. CDP location for the entire service area

The problem can be solved in other ways. Hakimi (1965) proposed a simple algorithm for determining a single median of network:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \ \forall i, j = 1, 2, \dots, n, \tag{6}$$

$$v_{ij} = d_{ij} * f_i, \quad \forall i, j = 1, 2, \dots, n, \tag{7}$$

$$s_j = \sum_{i=1}^{n} v_{ij}, \quad \forall j = 1, 2, \dots, n, \tag{8}$$

$$s^* = \min s_j, \tag{9}$$

Where x_i is the latitude of location of customer i, and y_i is longitude of that location.

First, a square matrix of the shortest distances between nodes d_{ij} is formed, where I are customers and j are the potential locations for the median (6). It is important to note that, unlike the previous model, where the actual distances between customers were used, in this case Euclidean, i.e. distances by "air line" were used. Then, the i-th row is multiplied by the number of deliveries for the customer i (7). Summarization is performed on the columns of the newly obtained matrix (8). In this way, the total "weighted" distances s_j from all customers to node j where CDP is located are obtained. Node with the minimum of the obtained values (s^*) (9) is median, i.e. CDP location.

Given the large number of nodes, the input data and the procedure for obtaining the solution will not be fully presented, but only the first quadrant of input data (matrix dimensions 5x5), which refers to zone 1, and intermediate results related to this zone will be shown (Table 3).

Table 3. Part of input data and intermediate results of algorithm application

customer	**1**	**2**	**3**	**4**	**5**
x coordinate	44.786901	44.785431	44.786467	44.786695	44.785487
y coordinate	20.460414	20.460468	20.461862	20.46345	20.463141
d_{ij}					
customer	**1**	**2**	**3**	**4**	**5**
1	0.00000	0.00147	0.00151	0.00304	0.00307
2	0.00147	0.00000	0.00174	0.00324	0.00267
3	0.00151	0.00174	0.00000	0.00160	0.00161
4	0.00304	0.00324	0.00160	0.00000	0.00125
5	0.00307	0.00267	0.00161	0.00125	0.00000
num. of requests	3	8	10	8	3
$v_{ij} = d_{ij} * f_i$					
customer	**1**	**2**	**3**	**4**	**5**
1	0	0.00441	0.00453	0.00913	0.00922
2	0.01177	0	0.01389	0.02591	0.02139
3	0.01512	0.01737	0	0.01604	0.01611
4	0.02434	0.02591	0.01283	0	0.00998
5	0.00922	0.00802	0.00483	0.00374	0

Vector of total "weighted" distances s_j, starting from the value of the sum of the distances of all customer to customer 1 in zone 1 to the sum of the distances of all customers to customer 5 in zone 7, is [1.2918; 1.1888; 1.0681; 0.9568; 0.8916; 0.8813; 0.8153; 0.9354; 0.9849; 1.1268; 1.1401; 1.0903; 0.9209; 0.8671; 0.8604; 0.7931; 0.7786; 0.7784; 0.8696; 0.9883; 1.3508; 1.3346; 1.5813; 1.737; 1.8563; 1.3954; 0.8959; 1.109; 1.327; 1.1554; 0.856; 0.898; 1.0569; 1.0716; 1.2136]. For the CDP, the household of customer 3 in zone 4 should be chosen, because this node corresponds to a minimum total "weighted" distance, which is 0.7784. The obtained solution is identical to the solution shown in Figure 3, obtained by applying the previously defined model.

4. CONCLUSION

The development of e-commerce also influences the development of different home delivery models. Thus, in recent years, delivery to CDPs has become increasingly important. The introduction of this delivery model aims to reduce flows, the number of engaged workers and vehicles, the number of vehicle deployment, energy consumption and costs, as well as the other economic, social and environmental benefits. CDPs can be a variety of purpose-built or existing facilities in traffic-friendly locations, including customer households.

This paper presents the procedure of locating CDPs, i.e. the selection of the customer household that will perform this function in the area of the City of Belgrade, using the p-median location problem. This achieved the basic goal and contribution of the paper. The paper provides an opportunity for future research. Comparative analysis of delivery parameters (mileage, operating time, vehicle utilization, costs, etc.) before and after the introduction of CDPs, as well as cases of introduction of one or more CDPs, should be the focus of future research to determine the effects of the introduction of these solutions. The possibility of applying the model to a real problem of larger dimensions (a larger number of service zones, customers, deliveries and CDPs) is also one of the directions of future research. In this context, the possibility of applying other problem-solving methods (e.g. heuristic and metaheuristic algorithms) should be explored.

ACKNOWLEDGMENT

This paper was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (projects TR36006 and TR36027).

REFERENCES

[1] Browne, M., Allen, J., Anderson, S, Jackson, M., (2001). Overview of home deliveries in the UK, University of Westminster and Freight Transport Association (FTA), a study for the DTI.

[2] Gevaers, R., Van de Voorde, E., Vanelslander, T., (2009). Characteristics of innovations in last-mile logistics-using best practices, case studies and making the link with green and sustainable logistics. In Proceedings of The European Transport Conference.

[3] Hakimi, S. L., (1965). Optimum distribution of switching centers in a communication network and some related graph theoretic problems. Operations research, 13(3), 462-475.

[4] Hakimi, S.L., (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. Operations Research, 12, 450–459.

[5] Hübner, A., Kuhn, H., Wollenburg, J., (2016). Last mile fulfilment and distribution in omni-channel grocery retailing. International Journal of Retail & Distribution Management, 44(3), 228–247.

[6] Lin, Y. H., Wang, Y., He, D., Lee, L. H., (2020a). Last-mile delivery: Optimal locker location under multinomial logit choice model. Transportation Research Part E: Logistics and Transportation Review, 142, 102059.

[7] Lin, Y. H., Wang, Y., Lee, L. H., (2020b). Parcel Locker Location Problem under Threshold Luce Model. arXiv preprint arXiv:2002.10810.

[8] Mladenović, N., Brimberg, J., Hansen, P., Moreno Pérez, J.-A., (2007). The p-median problem: a survey of metaheuristic approaches. European Journal of Operational Research, 179(3), 927–939.

[9] Morganti, E., Dablanc, L., Fortin, F., (2014a). Final deliveries for online shopping: The deployment of pickup point networks in urban and suburban areas. Research in Transportation Business & Management, 11, 23–31.

[10] Morganti, E., Seidel, S., Blanquart, C., Dablanc, L., Lenz, B., (2014b). The impact of e-commerce on final deliveries: alternative parcel delivery services in France and Germany. Transportation Research Procedia, 4, 178-190.

[11] Piplani, R., Saraswat, A., (2012). Robust optimisation approach to the design of service networks for reverse logistics. International Journal of Production Research, 50(5), 1424–1437.

[12] Punakivi, M., (2003). Comparing alternative home delivery models for e-grocery business, PhD thesis, Helsinki University of Technology, Industrial Engineering and Management, Helsinki.

[13] Song, L., Cherrett, T., McLeod, F., Wei, G., (2009). Addressing the last mile problem. Transport impacts of collection and delivery points. Transportation Research Record: Journal of the Transportation Research Board, 2097(1), 9–18.

[14] Tadić, S., Veljović, M., (2021). Home delivery: a framework for structuring. International journal for traffic and transport engineering – IJTTE, 11(1), 30 – 74.

[15] Tadić, S., Veljović, M., Zečević, S. (2022). Crowd logistics: household as a logistics service provider. International journal for traffic and transport engineering – IJTTE, 12 (1), 111 – 122.

[16] Teodorović, D. (2007). Transport networks (In Serbian), Faculty of Transport and Traffic Engineering, University of Belgrade

[17] Visser, J., Nemoto, T., Browne, M., (2014). Home Delivery and the Impacts on Urban Freight Transport: A Review, Procedia - Social and Behavioral Sciences, 125, 15–27.

[18] Wang, Y., Ong, T., Lee, L. H., Chew, E. P., (2017). Capacitated competitive facility location problem of selfcollection lockers by using public big data. In Automation Science and Engineering (CASE), 2017 13th IEEE Conference on, 1344–1344.

[19] Weltevreden, J. W. J., (2008). B2C e-commerce logistics: the rise of collection-and-delivery points in The Netherlands, International Journal of Retail & Distribution Management 36(8), 638–660.

[20] Wu, H., Shao, D., Ng, W. S., (2015). Locating self-collection points for last-mile logistics using public transport data. In Pacific-Asia Conference on Knowledge Discovery and Data Mining, Springer International Publishing, 498–510.

[21] Yuen, K. F., Wang, X., Ng, L. T. W., Wong, Y. D., (2018). An investigation of customers' intention to use self-collection services for last-mile delivery. Transport Policy, 66, 1–8.

[22] Zenezini, G., Lagorio, A., Pinto, R., Marco, A. De, Golini, R. (2018), The collection and delivery points implementation process from the courier, express and parcel operator's perspective. IFAC-PapersOnLine, 51(11), 594–599.