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OPTIMAL LOCATION ANALYSIS OF MICRO DISTRIBUTION CENTERS FOR LAST MILE DELIVERY

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Abstract: *Last mile delivery represents an intensely competitive business and the position of postal companies, as a traditional provider of this service, is under the increasing pressure. The aim of this paper is to provide a review of the current process of parcel deliveries of Public Enterprise Post of Serbia and to assess the possibility for introduction of alternative models. More precisely, for Belgrade urban area, we analyze the potential for transition from the current hub-and-spoke model to a multy hub distributed last mile delivery model which will be based on e-cycle logistics. Optimal location of micro hubs for last mile deliveries is formulated as a capacitated p-median problem. Proposed approach enables decision makers in postal sector to understand and conduct appropriate actions towards redesigning the current last mile logistics service to a new green logistics solution.*

Keywords: *micro hub location, last mile delivery, postal logistics, e-cargo bikes*

1. Introduction

Traditional roles of postal companies are to act as an intermediary between sender and recipient as well as to provide the last mile delivery service to the end customer. Nowadays, postal companies are faced up with challenges posed by new media and emerging ecommerce business models which contradict the traditional postal delivery model (Amazon and eBay for example). Therefore, seeking for alternative methods of last mile delivery as an intensely competitive business, represents a task of crucial importance to postal companies.

Some large European cities (for example Berlin, Amsterdam, Paris) as well as the U.S. cities (for example New York, Seattle, Chicago) are exploring ways to reduce congestion and CO2 emissions in urban areas. As a response to this initiative, posts and other delivery companies are seeking for the new logistics models for faster and more sustainable delivery (US Postal Service, 2018). The micro hub model as one of the most popular solutions involves redesign of the current last mile distribution model by trucking parcels to small depots or micro hubs from which local urban delivery is done faster and cleaner by cargo bikes (or carriers on foot). UPS for example[1], currently has several micro hub projects in operation (Munich, Frankfurt and Hamburg in Germany) where they operate mini distribution hubs in the city center, with service providers delivering packages from the hub by foot or e-cargo bicycles. Through these hubs, UPS has eliminated the use of diesel delivery vehicles in and around the city center which significantly contributed to reduced congestion and CO2 emissions (by up to 45% in micro hub project in Dublin).

Therefore, the aim of micro hubs is to reduce the amount of traffic related to the delivery of shipments and thus affecting the social, financial and sustainability related impacts. Micro hubs should be located close to the serving area with a good access to the strategic road network. Micro hubs serve smaller size areas and handle small and light weight goods. Large freight vehicles (vans and minivans) leave the shipments during the night or scheduled delivery windows. From the aspect of purpose and size, micro hubs can be low cost mobile micro hubs parked on the street, in parking garage or in the parking lot of existing retail stores. Their size depends on the demand density for a given area. Micro hubs can also be established at cycle logistics hubs which include space for short-term storage, sorting, entry/exit of cargo bikes and parking, loading/unloading operations and limited warehousing. Additional feature could be the possibility to accommodate one larger freight vehicle (truck, van) through additional parking and maneuvering space.

Delivery of postal express items on the territory of Belgrade is conducted through 22 postal units that perform specialized delivery. Postal express items are delivered to these organizational units directly from the main sorting center. Each of the 22 postal units covers a part of the territory of Belgrade, which includes tens and even hundreds of thousands of inhabitants. Vans and specialized cars are mainly used for the delivery of these postal items.

In this paper a new last mile logistics system will be proposed for the problem of parcels delivery of PE Post of Serbia on a case of Belgrade urban area. The problem of finding the optimal locations for micro hubs will be solved mathematically. The problem belongs to a class of facility location problems and can be modelled as a capacitated p-median problem. P-median problem is a classical combinatorial problem whose objective is to find p locations out of a set of potential locations for transhipment points such that the sum of weighted distances between each demand point and its closes facility is minimized. Capacity of each hub is limited. The distances between each demand point and its closest facility location will be weighted by the demand that is sent to that point.

The paper is organized as follows. After introduction, in Section 2, a literature review is given. Section 3 contains a proposal of new last mile distribution system of Serbian postal company for the Belgrade urban area. In Section 4. mathematical model for optimal hub location is explained. Numerical experiments are presented in Section 5. Section 6 contains concluding remarks.

2. Literature review

Cargo bikes can be used for courier, express, parcel services of a postal company in a monomodal or a multimodal logistics system (Assman et al., 2020). Monomodal system includes the use of cargo bikes as the sole transport mode. On the other side, multimodal system considers the use of cargo bikes in combination with other transport

[1] https://www.parcelandpostaltechnologyinternational.com/features/ups-champions-micro-hub-model-for-sustainable-urban-logistics.html

modes. These transport modes realize the transport from a hub to a micro consolidation center from which the inner city journeys are realized with cargo bikes. Micro Consolidation Points (MCP) represent transhipment points which should be located in and around medium to high density areas in a proximity to a consumer (20-30 minutes of cargo bike ride from MCP) which would enable a consolidation of shipments for the last mile delivery to a specific post code group. In this section a review of the relevant approaches for general facility as well as hub location problems is given.

In general, a facility location problem (FLP) includes a set of spatially distributed customers and a set of potential locations of facilities aiming to serve customer demands. Main questions to be answered are: (a) which facilities should be used (opened)? (b) which customers should be serviced from which facility (or facilities) so as to minimize the total costs? A number of practical constraints can be added to this general setting depending on specific application (Melo et al., 2009). In terms of the number of potential locations facility location problems can be modelled as discrete and continuous. In discrete case, the selection of locations for establishment of new facilities is restricted to a limited set of alternative locations. Discrete versions of facility location problems are modelled as p-median problems in which p facilities are to be selected to minimize the total (weighted) distances or cost for satisfying customer demands (Drezner and Hamacher, 2004; ReVelle and Eiselt, 2005; Daskin, 2013). In case when the cost of establishment of a facility differs from location to location, the objective function can be extended with a term for fixed facility location cost. Uncapacitated FLPs (UFLP) have no limit in its capacity and each customer is assigned to exactly one facility. On the other side, capacitated FLPs (CFLPs) as an extension UFLP limit the maximum demand that can be fulfilled from each potential facility. A comprehensive review of discrete FLPs is provided by Ulukan and Demircioglu (2015). In continuous FLPs (ConFLP) location space there is unlimited number of potential places for siting facilities (Carlo et al., 2012). In terms of the capacity, both, ConFLP and DFLPs can be divided capacitated and incapacitated FLPs. Uncapacitated FLPs (UFLP) have no limit in its capacity and each customer is assigned to exactly one facility. On the other side, capacitated FLPs (CFLPs) as an extension UFLP limit the maximum demand that can be fulfilled from each potential facility. The above mentioned models can be distinguished in terms of planning horizon (single or multi-period), and in terms of stochasticity (customer demands and costs can be treated as certain or uncertain parameters). Snyder (2006) made a comprehensive review of stochastic facility location problems. Hub location problem (HLP) is a relatively recent extension of traditional facility location problems. Hubs represent facilities which serve for consolidation, connection or switching of flows between origins and destinations (Farahani et al., 2013) and their introduction significantly improves the efficiency of the logistics network. Similar to FLPs, there is a difference of HLPs on continuous and discrete, uncapacitated and capacitated, by the cost of locating a hub node, as well as against some additional criteria such as the number of hub nodes (single or multiple), the cost of connecting non-hub nodes to hub nodes (zero cost, fixed cost, variable cost) and on source determining the number of hubs to locate (pre-specified or not pre-specified). Depending on these specific features, HLPs can be decomposed on median, center, covering, set covering or maximum covering. Different exact, heuristic as well as metaheuristic solution algorithms are used for solving HLPs. An excellent review of models, classification, solution techniques and applications is given in Farahani et al. (2013).

In this paper, the problem of cargo bike hub location for a postal operator is studied, and an exact solution approach based on integer programming model is proposed. Proposed approach is validated on a network example of the central district in Belgrade (Serbia) with a set of micro hub locations.

3. Last mile distribution system of PE Post of Serbia

Due to rapid increase of eCommerce and raising expectations of consumers in terms of fast and low cost delivery, parcel carriers are faced with financial challenges in providing the last mile delivery (Mabe, 2016). In comparison with traditional distribution system (where the delivery to retailer is optimized), eCommerce doesn't enable optimization of truckloads due to the smaller shipments which are transported directly to consumers' homes. Consumers expect fast delivery (same-day or next-day) and flexible delivery options (time-windows, delivery points). In contrast to retailers and parcel carriers which face with increasing costs, due to added technology and logistics infrastructure, consumers have benefits in terms of more choices, easy price comparison, conveniencence and lower costs. From the aspect of society, there is increased pollution, traffic congestion and safety.

The segment of postal express items in Serbia has a constant growth of about 10% per year. In recent years, these items have accounted for about 12% of the total volume of postal items and, more importantly, about 47% of total revenue. When it comes to postal items that is the result of e-commerce - they have been growing steadily for many years, over 20% per year. In recent years, these postal items account for about 30% of PE items, or about 4% of the total volume of postal items in Serbia. There is also a significant share in the revenue of postal items from e-commerce, which is about 30% of the revenue of PE items, or about 14% of the total revenue of all postal items in Serbia.[2]

The solution for this problem lies in the transformation of last mile distribution system of PE Post of Serbia, from a traditional hub-and-spoke model to a multy-hub distributed last mile delivery model. New, multy-hub distributed delivery model should be based on integration of cargo bicycles into logistics process on those markets (courier, express and parcel service (CEP) specifically) and cities (city districts) where that is economically feasible. In comparison with traditional distribution model (Figure 1a.), new model will include flexible consolidation points or micro hubs located in and around medium to high density areas (Figure 1b.).

Micro hubs should serve a radius appropriate for the density of the area and allow the delivery of packages to the consumers within 15-20 minute bike ride from the hub. The size of the delivery area around a hub can vary in size (from 500 m to 10 km) and depends on the CEP service and its local consignment structure, for example route and delivery characteristics.

Micro hubs can be mobile, semi stationary or stationary and located in a wide variety of private or public spaces (parket on the street, in parking lot of retail stores, or in a parking garage). In terms of access rights, micro hubs can be non cooperative (open for only one logistics operator, national post office for example) and cooperative (used by

[2] Source: Overview of the telecommunications and postal services market in the Republic of Serbia in 2019

several logistics providers). Cooperative micro hubs may involve consolidation of parcels from multiple carriers based on sharing economy business models.

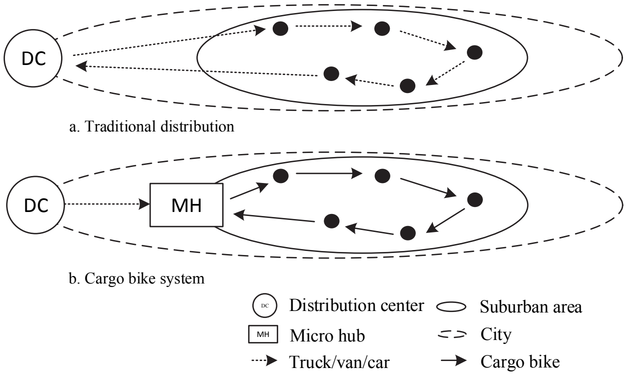

Figure 1. Last mile distribution system

Optimal location of micro hubs represents one of the stages in the development of urban electric cargo bike system (Milenkovic et al., 2020) and according to literature review can be treated as a facility location problem (with different variations) and solved on different ways. In next section we formulate a capacitated p-median model for optimal micro-hub location.

4. Capacitated p-median model for optimal micro-hub location

The problem of micro-hub location for e-cycle last mile distribution system of PE Post of Serbia can be formulated as a capacitated p-median problem. In capacitated p-median problem p-capacitated medians are selected to serve a set of customers so that total assigned demand to each of the candidate medians satisfies the capacity limitation of facilities (Ghoseiri and Ghannadpour, 2007). Therefore, the capacitated FLP can be formulated as follows.

$$Minimize \sum_{i\in I}\sum_{j\in J} d_j c_{ij} x_{ij} \tag{1}$$

Subject to:

$$\sum_{j\in I} x_{ij} = 1,\ i \in I \tag{2}$$

$$\sum_{i\in I} y_i = p \tag{3}$$

$$\sum_{j\in J} d_j x_{ij} \le Q_i y_i,\ i \in I, j \in J \tag{4}$$

$$y_i \in \{0,1\};\ i \in I \tag{5}$$

$$x_{ij} \ge 0,\ i \in I, j \in J \tag{6}$$

Where:

$I = \{1,...,m\}$ is the set of candidate locations for micro hubs;

$J = \{1,...,n\}$ is the set of customer locations;
p : the number of micro hubs to introduce;
d_j : the size of demand at customer j ;
c_{ij} : allocation cost from micro hub location i ($i \in I$) to the customer location j ($j \in J$);
Q_i : capacity of micro hub $i \in I$.

Decision variables are:

$$y_i = \begin{cases} 1 \text{ if a micro-hub facility is located at candidate site i} \\ 0 \text{ otherwise} \end{cases}$$

x_{ij} : the fraction of the demand of customer j that is supplied from facility i

The objective function (1) minimizes the demand weighted total cost. According to constraints (2) all the demand of customer j must be satisfied. Excatly p facilities must be selected by the solution according to constraints (3). Constratins (4) state that the customer can be located to open facilites satisfying also the capacity limitations of these facilities. According to constraints (5) and (6), location variables as well as assignment variables must be binary and non-negative, respecitvely.

This formulation can be solved to optimality for small instances (up to 1000 demand/facility nodes) by exact solution approaches. For larger instances, the required time of these exact approaches becomes prohibitively large and numerous heuristic (classic-, meta- and math- heuristic) solution approaches have been proposed (Gnagi and Baumann, 2021).

In this section we formulate also the Lagrangian Relaxation (LR) algorithm to the capacitated p-median problem (Daskin and Maass, 2015). The advantage of Lagrangian relaxation over heuristic approaches is based on the fact that, as first, at every iteration of the Lagrangian procedure we obtain lower and upper bounds on the objective function value, and as second, the Lagrangian method can be embedded in a branch and bound algorithm to obtain provably optimal solutions.

In order to apply Lagrangian Relaxation method we relax the constraint (2) that enforces all the customer demant to be satisfied. Resultant Lagrangian problem looks like follows:

$$\begin{aligned} Max_{\lambda} Min_{x,y} F &= \sum_{i \in I} \sum_{j \in J} d_j c_{ij} x_{ij} + \sum_{j \in J} \lambda_j (1 - \sum_{i \in I} x_{ij}) \\ &= \sum_{i \in I} \sum_{j \in J} (d_j c_{ij} - \lambda_j) x_{ij} + \sum_{j \in J} \lambda_j \end{aligned} \tag{7}$$

Subject to (3)-(4).

For any given λ we can find optimal solution by following set of steps:

1. **Providing lower bound on the objective function value:**
   1.1 For all $i \in I$ compute $V_i = \sum_{j \in J} \min\{0, d_j c_{ij} - \lambda_j\}$;

1.2 Sort candidate locations by the value of V_i, select the p most negative V_i values and set location variables $y_i = 1$ for these candidate locations.

1.3 Set assignment variables x_{ij} to 1 if $y_i = 1$ and $d_j c_{ij} - \lambda_j < 0$ and 0 in oposite case.

2. Obtaining an upper bound and finding a feasible solution

2.1 Fix y at the solution and assign each node to the nearest facility for which $y_i = 1$.

Subgradient optimization can be used to update the Langrangian multiplier λ_k at each iteration k as follows:

$$\lambda_j^{k+1} = \lambda_j^k + t_k (1 - \sum_{i \in I} x_{D_{ij}}^k) \tag{8}$$

t_k is the step size determined as follows:

$$t_k = \frac{\theta_k \left(Z_{UB} - Z_D(\lambda^k) \right)}{\sum_{j \in J} \left(1 - \sum_{i \in I} x_{D_{ij}}^k \right)^2} \tag{9}$$

Where Z_{UB} is the best upper bound, $x_{D_{ij}}^k$ is the element at (i, j) of the solution x_D^k to the Lagrangian problem at iteration k, and $\theta_k \in (0, 2]$ is a scalar (Daskin, 2013).

5. Numerical experiments

Proposed capacitated p median model is tested on a real-world case study of the Old Town district in Belgrade (Serbia) with a set of feasible micro-hub locations. Old Town district represents one of the main toursitic attractions in Belgrade, where great number of restaurants, shops and other touristic objects is located. The area is closed for heavy vehicles, the supply of the objects located in the district is allowed from 9 a.m. to 2 p.m. and from 6 p.m. to 7 a.m. under the condition that light good vehicles (up to 3.5t) occupy the road at most for 15 minutes.

Micro hub location for the bikes delivery system in Old Town of Belgrade should be selected from the set of alternative variatns that satisfy the conditions of transport accessibility for cargo bicycles as well as for conventional vehicles. Architectural features of historic buildings in the area should also be considered.

In order to validate the applicability of the proposed approach we selected 5 potential micro-hub locations (Table 1.) for serving the set of 20 customers in the Old town district (Figure 2.).

Table 1. The alternative locations of a micro hub in the Old Town of Belgrade

Micro hub locations	**Longitude**	**Latitude**	**Addresss of location**
1	44.82558	20.45836	Visokog Stevana str.
2	44.82413	20.46028	Skendrebegova str.
3	44.82344	20.45665	Rige od Fere str.
4	44.82579	20.46098	Despota Đurđa str.
5	44.82304	20.46068	Cara Dušana str.

Figure 2. Locations of clients and potential micro hub locations (red circles) in the Old Town district of Belgrade

Using the proposed approach, capacitated p-median model that considers the streets available for bicycles was validated for the district of Belgrade Old Town. Initial data (locations of clients, potential hub locations, and cargo bike routes) were obtained by the means of OSRM API (Luxen and Vetter, 2011).

For assumed customer demand and capacities of potential micro-hub locations, and allocation costs proportional to bike-based travel distance (obtained via OSRM API), we calculated the optimal solution to the problem of *p* facilities (Table 2.). Lagrangian relaxation found the same optimal solution as monolithic approach.

Table 2. Median results for micro-hub location problem

p	Demand weighted average distance	Change	Locations	No of iterations of LR
1	3494		1	4
2	2984	510	1, 3	9
3	2889	95	1, 3, 4	63
4	2844	45	1, 2, 3, 4	20
5	2844	0	1, 2, 3, 4, 5	24

Computation time for this instances is inignificant (up to 1 sec) in both cases. Based on the results, it there exists an optimal solution to the problem with *p* facilities, then adding a $p+1^{st}$ facility at any of the candidate nodes that doesn't have a facility, will decrease the total cost or distance and therefore will also decrease the objective function. More precisely, marginal improvement in demand weighted cost is monotonically decreasing as we add micro hubs (column "change").

The last column shows the number of iterations until reaching the optimal solution. Figure 3. shows the progression of LR algorithm for the case *p=3*. The lower bound kept increasing and reached at the same bound in the 63th iteration.

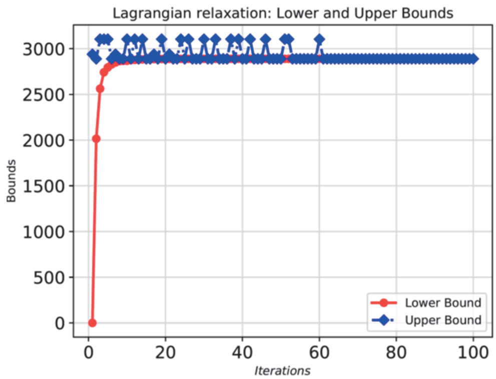

Figure 3. LR method: iterations

6. Concluding remarks

Well planned last mile cargo bike cargo bike delivery system can significantly improve urban livability by improving air quality, decreasing CO2 emissions and congestion in urban districts. In order to maximize these effects, before establishing the cargo bike network it is needed to carefully plan the network configuration. Location of transhipment nodes significantly impacts on the efficiency of cargo bike solution. In this paper, for a hypotethical set of clients and potential hub locations based on a real-world case study of the Old Town district in Belgrade (Serbia) we demonstrated the applicability of capacitated p-median model for determining the optimal micro hub locations. Besides the monolithic formulation which is suitable for smaller instance, applicability of LR-based model is proven which can be used for medium and larger instances. Besides the testing on larger instances, future work will be dedicated to further improvements of the formulation based on consideration of changing demand (dynamic p-median problem) and stochastic demand (stochastic p-median problem).

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[16] Overview of the telecommunications and postal services market in the Republic of Serbia in 2019

Rezime: *Logistika poslednjeg kilometra predstavlja vrlo konkurentno tržište i poštanski operatori, kao tradicionalni pružalac ove usluge, se suočavaju sa rastućim pritiskom da zadrže svoju tržišnu poziciju. U ovom radu analiziran je process distribucije pošiljaka na poslednjem kilometru i predložen novi model koji se zasniva na zelenoj logistici. Preciznije, na primeru gradskog centra Beograda, analizirana je mogućnost prelaska sa trenutnog "hub-and-spoke" modela na "multi-hub" distribuirani model uručenja zasnovan na logistici električnih kargo bicikala. Problem određivanja optimalne lokacije mikro distributivnih centara (habova) formulisan je kao kapacitativni problem p medijana. Predloženi pristup omogućava donosiocima odluka u poštanskom sektoru da razumeju i sprovedu odgovarajuće akcije usmerene ka transformaciji postojeće logističke usluge u zeleni logistički sistem.*

Ključne reči: *lokacija mikro distributivnih centara, distribucija pošiljaka na poslednjem kilometru, poštanska logistika, električni kargo bicikli.*

ODREĐIVANJE OPTIMALNE LOKACIJE MIKRO DISTRIBUTIVNIH CENTARA ZA URUČENJE NA POSLEDNJEM KILOMETRU

Miloš Milenković, Nikola Knežević, Nebojša Bojović