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Dynamic assignment of loading bays for efficient urban last mile deliveries

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Abstract

Urban freight deliveries are facing problems of limited accessibility to customers located in the city centre. Due to lack of loading bays, freight vehicles are forced to double parking or circulating in the city centre to find an available loading bay. To solve that problem a model for dynamic management of urban last mile deliveries has been developed. The optimisation is based on fuzzy c-means clustering of customers to dynamically assign the best possible loading bay in combination with a two-echelon routing algorithm. The model is tested on the actual data of deliveries to the historical city centre of Lucca, Italy. Results of simulations have proven significant savings of the total travel time and distance in comparison to the existing situation. The suggested approach is highly flexible and allows adaptation to any city access restriction scheme.

Keywords: city logistics, facility location, vehicle routing, optimisation

Dinamičko dodjeljivanje slobodnih mjesta vozilima za učinkovitu dostavu do vrata

Sažetak

Dostava teretnim vozilima u urbanim sredinama, a posebno u centre gradova, je otežano ograničenim pristupom korisnicima usluga dostave. Zbog manjka područja za utovar, dostavna se vozila parkiraju na nedozvoljenim područjima ili cirkuliraju dok ne nađu slobodno mjesto. U ovom je radu predstavljeno rješenje tog problema pomoću modela za dinamičko upravljanje dostave do vrata (*last mile delivery*). Optimizacija u modelu izvedena je preko algoritma c-sredina (*fuzzy c-means clustering*) koji dinamički pridjeljuje svakog korisnika na najbolje dostupno područje za utovar u kombinaciji s algoritmom za navođenje u dvije razine. Model je testiran sa stvarnim podacima o dostavama u centru grada Lucca u Italiji. Rezultati simulacija upućuju na značajnu uštedu ukupnog vremena dostave u odnosu na trenutačno stanje. Opisani pristup je izrazito fleksibilan i dopušta uvođenje dodatnih prometno ograničavajućih shema.

Ključne riječi: gradska logistika, položaj usluge, navođenje vozila, optimizacija

1. Introduction

Increasing demand of customers and constant growth of urban areas are fundamentally changing conditions and possibilities for efficient urban freight deliveries. New trends of just-in-time deliveries and e-commerce result in high fragmentation of urban freight delivery demand, which increases the number of poorly utilised urban freight transport trips and decreases the efficiency of urban freight deliveries. Recent empirical studies estimate that urban freight vehicles account for 6 to 18 percent of a total number of vehicles in cities; 10 to 15 percent of vehicle-kilometres and about 20 percent of energy use and CO2 emissions [1,2]. Freight vehicles also contribute significantly to urban traffic congestion; they cause a reduction of available road capacity and contribute significantly to urban traffic pollution [3]. In Europe, more than 20 percent of distribution vehicles in urban areas drive empty and the average load factor is only at about 30-40 percent [4,5].

These problems are most severe in city centres, and many cities are therefore implementing access restriction schemes to limit traffic congestion in the city centres [6]. Part or the entire city centre is often categorized as a pedestrian zone, which additionally limits the accessibility of freight vehicles to customers located in the city centre. In case customers are not accessible by freight delivery vehicles, loading bays (LBs) are needed for transhipment of parcels and parking of delivery vehicles near customers (mainly on the border of pedestrian zone) for the time being of last mile delivery operations. Last mile delivery is predominantly done on foot or by trolley [7].

Urban areas are in general confronted with scattered LBs and many of them are often occupied (sometimes by other delivery vehicles, but in most cases illegally from individual users) [8,9]. Delivery vehicles which are not able to find available LB are forced to double parking or cruising for parking, which is time-consuming and contributes significantly to the reduction of available road capacity and urban traffic congestion [10–13].

This article is dealing with the problem of defining the most optimal number and location of LBs in urban areas, their selection, considering dynamically changing access restrictions, and optimal vehicle routing for efficient urban last mile deliveries. The first part of the article is dedicated to reviewing of the urban freight LB solutions and initiatives, following by presentation of an algorithm for dynamic management of urban freight deliveries. The final section is devoted to proving efficiency of the proposed approach referring to simulation on the real case study data.

2. Review of urban loading bay solutions and initiatives

LBs should be understood as places within the urban area, where the delivery vehicles can stop to perform parking, transhipment and last mile delivery operations [14]. Initiatives referring to LBs should not be considered only as infrastructure (physical) measures but also as soft measures dealing with management, reservation, and enforcement of loading bays use [14,15].

Delivery area management approaches have been extensively studied by Patier et al. [12] highlighting the importance of providing the most appropriate in-the-field information system (or device) to inform all users of the situation (occupancy) of each loading bay. McLeod and Cherrett [16] investigated the impact of advanced booking of LBs and noticed the high level of sensitivity to early or late arrivals. In this case the capacities of LBs may be reduced significantly. Therefore, they suggest opting for more dynamic LB reservation systems.

Different LB management solutions have been recently tested in European cities. Lyon was involved in an experiment called "loading bay of the future" that allowed operators to reserve the space 24 hours in advance. This, in turn, led to more efficient trips and routes in the city and resulted in 40% reduction in double parking for deliveries, less congestion, and pollution in the city centre [8]. Vienna experimented with the project "i-Ladezone" aiming to address intelligent monitoring of LBs in an urban environment. The project developed different management methods for efficient and effective monitoring of the occupancy of LBs by delivery vehicles and private cars and trying to keep LBs at maximum availability to reduce impacts on traffic caused by the loading activities [17]. Lisbon, within the frame of Straightsol project, tested two technological based schemes; adopting parking meters for loading/unloading operations and loop vehicle detection sensors installed on the ground of LBs. They are expecting to reduce the number of parking infractions, reduce the average duration of freight operations, and increase transport operators' and shopkeepers' satisfaction [18].

All above-mentioned examples noted the need for further research and testing towards dynamic LB management, reservation, and implementation of remote monitoring technology for LB control. This process should be additionally supported by the efficient information system that enables also real-time vehicle routing and navigation.

3. On algorithm for dynamic management of urban freight deliveries

A new algorithm and model are developed to overcome problems and needs for better management of LBs identified in the literature and in the above-presented case studies. The algorithm is shortly presented in the sequel (see Figure 1). A more detailed elaboration and explanation of the algorithm and model developed in MATLAB can be found in Letnik et al. [7].

Generally, last mile delivery problem is divided into two sub-problems: (1) the delivery of goods from outside the city to the LB; and (2) the delivery of goods from the LB to the customer. This is the so called "two echelon problem". In the model both sub-problems are resolved in a reversed order.

(1) In the first sub-problem the best LB is determined with a fuzzy clustering algorithm (FCM), which considers the space continuum, yielding each point of the space as a potential final position of a LB. Considering the practical constraint to make only a limited number of specific locations as potential LB, cluster centres (resulting from the clustering algorithm) must be approximated to the most appropriate (acceptable) location/s which are physically available.

Two different approximation methods are considered. In the first approximation method, only the best potential LB (the closest to the cluster centre) is considered as acceptable. The LB is considered as acceptable for a customer if the walking distance from the LB to the customer does not exceed some (fixed chosen) distance (d_{max}). In the second approximation method, a set of acceptable LBs are taken into consideration.

The aim of the second approximation method is to make the system more flexible, especially in the peak periods when the demand is bigger than the LBs capacities. For this purpose, Fuzzy c-means (FCM) procedure has been implemented because it permits the overlapping of clusters and more flexible selection of LBs. The clustering procedure is searching for a maximum acceptable (walking) distance from the LB to the customer. Clustering is successful if distances from cluster centre to all members of the cluster are all equal or less than d_{max}.

(2) In the second sub-problem we take advantage of the results obtained when solving the first sub-problem. Selection of the LB depends on the strategy of choosing the approximation method. In the case of the first approximation method, the nearest LB is selected and considered as the most optimal one. In the case of the second approximate method, the algorithm chooses among all the acceptable LBs considering their occupation and the shortest possible path.

The routing is in both cases performed based on the Dijkstra algorithm. The routing algorithm compares travel distances among origins (entrance points to the urban area) and destinations (acceptable LBs). The most optimal (shortest/fastest) route is finally selected in combination with best or acceptable LBs. Routing algorithm also has a function of keeping vehicles outside the city in the case and until all acceptable LBs are occupied.

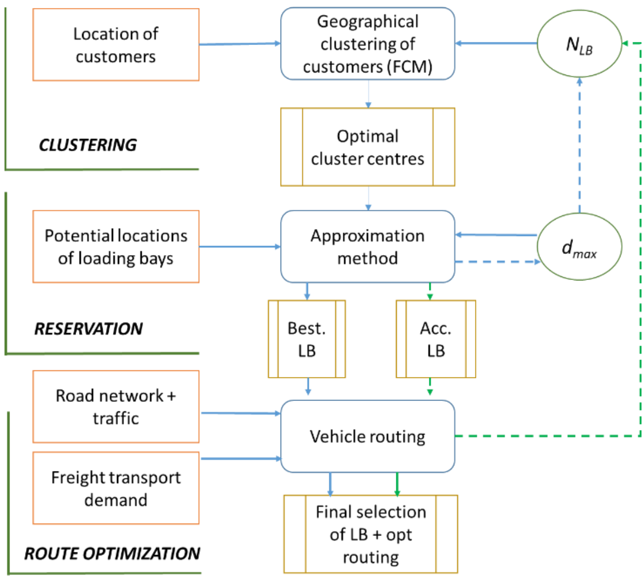

Figure 1. The Architecture of the proposed algorithm

As seen from Figure 1, location of customers (geographical coordinates) and a predefined number of LBs (N_{LB}) are two main elements needed for clustering procedure and defining

the optimal location of LBs (cluster centres). In the model, N_{LB} is determined based on the maximum allowed distance from the LBs to the assigned customers (d_{max}).
The best LBs produced by the first approximation method and the acceptable LBs produced by the second approximation method are determined according to the potential location of LBs and the value of d_{max}. If approximation methods do not result with finding a LB for all customers, then the d_{max} is increased and clustering algorithm runs again. The procedure is repeating until all the customers are belonging to at least one (acceptable) LB.
When decided on the scenario of the acceptable LBs, vehicle routing aims to find the shortest possible path from outside the city to the LB acceptable for a particular customer. The routing algorithm considers road network and traffic conditions relevant for a particular period of the day. At the end of the procedure, the routing algorithm determines which of the acceptable LBs results with the shortest and fastest path and select this LB as optimal.

4. Application of the model to a real case

The model has been applied to a real case study of a historical city centre of Lucca in Italy. The city of Lucca is one of the most advanced historical cities referring to the application of city logistics policies and measures. Consequently, many data have been available, and this presents a good basis for modelling purposes and testing of the proposed model. In addition to that, city of Lucca is planning to establish LBs in city centre, therefore, additional research on the field is needed.
Lucca city centre is a flat oval area, with the diameters of around 1.8 and 1.0 km. Access to the city centre is restricted with Limited Traffic Zone (LTZ) and differs with different time periods of the day. The number of commercial activities in Lucca city centre is 1.161, the average number of daily deliveries is 1272, and the number of commercial vehicles entering in the city centre is 1058 [DIB 08]. These numbers result in around 1.2 deliveries performed by each vehicle. In the model, we, therefore, assume that each freight vehicle performs only one stop in the historical city centre of Lucca.
Most of the deliveries are performed in the following three periods of the day: early morning (from 8 to 10 a.m.) 26.9%, late morning (from 10 to 12 a.m.) 29.1% and afternoon (from 4 to 6 p.m.) 15.7% [19]. We have decided to simulate only these three periods also because in these periods different access restrictions apply, which also results in the availability of a different number of LBs (some locations of loading bays are not accessible during particular periods of the day). These characteristics have been used to simulate dynamically changing conditions for urban freight deliveries.
The modelling and optimization process leading to results of optimal LBs assignment and routing can be best presented with the following scheme (Figure 2).

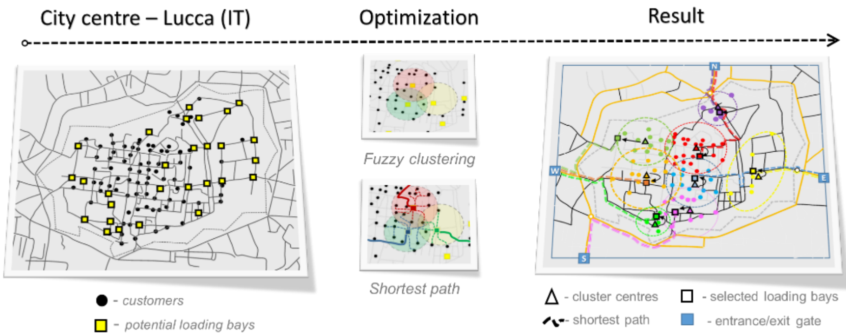

Figure 2. Schematic presentation of the model application

In the first phase, three different directed weighted graphs embedded in the plane have been established in MATLAB to simulate a road network of the city of Lucca. Weights correspond to distances and/or time required for traversing each section of the road network. Weights differ depending on the amount of traffic and pedestrian flows characteristic for different periods of the day.

In the second phase, we identified all customers located in the city centre and discretized their positions to the road sections of 100m. A number of deliveries to specific locations depend upon the number of customers belonging to particular road sections. Number, location, and capacity of potential LBs have been selected based on real physical constraints within the city centre and accessibility of locations with urban freight vehicles.

As already described, optimization has been performed with fuzzy clustering (FCM) of customers and two approximation methods for assigning cluster members to acceptable LBs. This procedure was done in combination with the shortest path algorithm that determined not only the shortest route within the city centre but also a selection of the best possible entrance gate for each individual delivery.

4.1. Achieved results

Performance of the system is compared: for the existing scenario (present situation) and two approximation methods (management strategies) and for the morning (8-10 a.m.), late morning (10-12 a.m.) and afternoon (4 – 6 p.m.) scenario.

Table 1. Comparison of performances - existing scenario and two management strategies

PERFORMANCE		Existing scenario			1st mng. strategy			2nd mng. strategy		
		Early morning	Late morning	After-noon	Early morning	Late morning	After-noon	Early morning	Late morning	After-noon
Max travel time	min/trip	51.0	51.0	80.0	30.0	23.0	31.0	30.0	23.0	31.0
Avg. travel time	min/trip	23.4	23.2	37.0	17.0	15.6	20.7	15.4	14.5	18.6
Max distance	km/trip	17.0	15.9	15.3	10.6	10.6	10.6	10.6	10.6	10.6
Avg distance	km/trip	9.6	9.5	9.5	6.1	5.9	6.1	5.6	5.5	5.5

As seen in Table 1, the most significant decrease, in commercial vehicles travel times, is shown in the afternoon scenario, when also the highest pedestrian flows are registered. The average travel time decreased from 37 to 20.7 minutes (44%), when the first management strategy is applied, and to 18.6 minutes (50%) when the second management strategy is applied; while the maximum travel time decreased from 80 to 31 minutes (61%) in both cases.

A better performance of the system is evident also from the travel distance point of view. Actually, the average distances decrease from 9.5 km to 6 km (36%), when the first management strategy is applied, and to 5.5 km (42%) in case of the second management strategy. The maximum distance travelled by freight vehicles, equal to 17 km, is shown in the early morning period of the existing scenario: but it decreases to 10.6 km when the two management strategies are applied.

In addition to that, two compared management strategies are resulting with different performance in walking distances of deliverer (from LBs to customers) and waiting time of delivery vehicles before entering the city centre. In the case of the first approximation method (only the best LB - the closest to the cluster centre is selected): average walking distances are only at about 70 meters, but vehicles have to wait outside the city centre for approximately 30 minutes on average. If the second approximation method is used (the algorithm chooses among all the acceptable loading bays – not only the closest one): the average walking distance is around 300 meters, but vehicles almost never wait outside the city before performing the deliveries. For the more detailed description of the model and results please see [7].

5. Conclusions

The last mile freight delivery system for urban areas, and a model to optimise its performances have been developed and presented. The model is centred on a clustering algorithm and two approximation methods to dynamically select the best possible LB and the most optimal routing for efficient urban last mile deliveries. The proposed model has been tested on the case of the small historical city centre and provide considerable savings in travel time and travelled distances.

References

[1] Schoemaker, J., Allen, J., Huschenbeck, M., Monigl, J.: Quantification of Urban Freight Transport Effects. BESTUFS Project: 2006.

[2] Figliozzi, MA.: The impacts of congestion on commercial vehicle tour characteristics and costs. Transp Res Part E Logist Transp Rev 2010;46:496–506. doi:10.1016/J.TRE.2009.04.005.

[3] Russo, F., Comi, A.: City Characteristics and Urban Goods Movements: A Way to Environmental Transportation System in a Sustainable City. Procedia - Soc Behav Sci 2012;39:61–73. doi:10.1016/j.sbspro.2012.03.091.

[4] Domínguez, A., Holguín-Veras, J., Ibeas, Á., dell'Olio, L.: Receivers' Response to New Urban Freight Policies. Procedia - Soc Behav Sci 2012;54:886–96. doi:10.1016/j.sbspro.2012.09.804.

[5] Bozzo, R., Conca, A., Marangon, F.: Decision Support System for City Logistics: Literature Review, and Guidelines for an Ex-ante Model. Transp Res Procedia 2014;3:518–27. doi:10.1016/j.trpro.2014.10.033.

[6] Bontempo, AP., Cunha, CB., Botter, DA., Yoshizaki, HTY.: Evaluating Restrictions on the Circulation of Freight Vehicles in Brazilian Cities. Procedia - Soc Behav Sci 2014;125:275–83. doi:10.1016/j.sbspro.2014.01.1473.

[7] Letnik, T., Farina, A., Mencinger, M., Lupi, M., Božičnik S.: Dynamic management of loading bays for energy efficient urban freight deliveries. Energy 2018;159:916–28. doi:10.1016/J.ENERGY.2018.06.125.

[8] Browne, M., Allen, J., Nemoto, T., Patier, D., Visser, J.: Reducing Social and Environmental Impacts of Urban Freight Transport: A Review of Some Major Cities. Procedia - Soc Behav Sci 2012;39:19–33. doi:10.1016/j.sbspro.2012.03.088.

[9] Muñuzuri, J., Cuberos, M., Abaurrea, F., Escudero, A.: Improving the design of urban loading zone systems. J Transp Geogr 2017;59:1–13. doi:10.1016/j.jtrangeo.2017.01.004.

[10] Silva, J., Alho, A.: Using Structural Equations Modelling to explore perceived urban freight deliveries parking issues. Urbe 2015 2015:1–20.

[11] Alho, A., Silva, J., Sousa, JP de.: A State-of-the-Art Modeling Framework to Improve Congestion by Changing the Configuration/Enforcement of Urban Logistics Loading/Unloading Bays. Procedia - Soc Behav Sci 2014;111:360–9. doi:10.1016/j.sbspro.2014.01.069.

[12] Patier, D., David, B., Chalon R., Deslandres, V.: A New Concept for Urban Logistics Delivery Area Booking. Procedia - Soc Behav Sci 2014;125:99–110. doi:10.1016/j.sbspro.2014.01.1459.

[13] Gardrat, M., Serouge M.: Modeling Delivery Spaces Schemes: Is the Space Properly used in Cities Regarding Delivery Practices? Transp Res Procedia 2016;12:436–49. doi:10.1016/j.trpro.2016.02.077.

[14] Alho, AR., Silva, J.: Analyzing the relation between land-use/urban freight operations and the need for dedicated infrastructure/enforcement — Application to the city of Lisbon. Res Transp Bus Manag 2014;11:85–97. doi:10.1016/j.rtbm.2014.05.002.

[15] Janjevic, M., Ndiaye, AB.: Which lines of action for local authorities to decrease the environmental impact of the urban freight transport? Wctr 2013.

[16] McLeod, F., Cherrett, T.: Loading bay booking and control for urban freight. Int J Logist Res Appl 2011;14:385–97. doi:10.1080/13675567.2011.641525.

[17] Chloupek, A.: i-Ladezone: Intelligent monitoring of loading bays in Vienna. Bestfact 2013.

[18] Cherrett T., Allen J., McLeod F., Maynard S., Hickford A., Browne M.: Understanding urban freight activity – key issues for freight planning. J Transp Geogr 2012;24:22–32. doi:10.1016/J.JTRANGEO.2012.05.008.

[19] Di Bugno, M., Guerra, S., Liberato, A. & Ambrosino G.: CEDM - Centre for Eco- City Freight Distribution. Un approccio integrato alla city logistics. Lucca. Lucca: 2008.