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ENERGY ASPECTS OF URBAN LAST MILE DELIVERY

ENERGETSKI VIDIKI DOSTAV V MESTIH

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Abstract

Cities are growing and, consequently, so is the need for a more efficient supply system to customers located in urban areas. Increasing traffic congestion is hindering the efficiency of deliveries in city centres, which also negatively influences the energy aspects of transport processes. This paper considers an efficient solution for optimizing urban freight deliveries and presents the results of a case study for a small historical city centre. A tool is based on optimal vehicle routing and the assignment of the most optimal loading bay. It results in considerable savings in travel time, travel distance, and energy.

Povzetek

Mesta se povečujejo in posledično tudi potrebe po učinkovitejši oskrbi kupcev v urbanih območjih. Povečanje prometnih zastojev ovira učinkovitost dostav v mestnih središčih, kar negativno vpliva tudi na energetske vidike transportnih procesov. V članku je predstavljena učinkovita rešitev za optimizacijo dostav v mestih. Predstavljeni so tudi rezultati optimizacije dostav v mestno središče na primeru majhnega zgodovinskega mesta. Optimizacija temelji na učinkovitem vodenju dostavnih vozil in dodeljevanju najprimernejšega dostavnega mesta. Prikazan je precejšen prihranek pri času vožnje, prevoženi razdalji in porabljeni energiji.

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1 URBAN FREIGHT TRANSPORT AND ENERGY CONSUMPTION

High energy consumption and the negative effects of its use are currently one of the main concerns of the European Union (EU), *[1]*. Several policies, regulations, and initiatives have been launched to reduce energy demand, increase the share of renewable energy sources and improve energy efficiency, *[2]*, *[3]*. All these measures have helped to reduce total energy consumption in most sectors, except in transport, which remains the fastest growing consumer of energy and producer of greenhouse gases in the world, *[4].*

The share of final transport-related energy consumption in comparison to other sectors in the EU is presented in Figure 1.

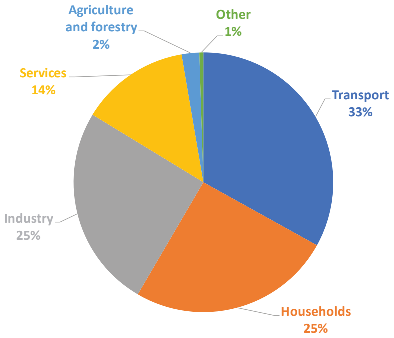

Figure 1: *Share of total final energy consumption, EU-28 (2015),* [5]

In Europe, the transport sector consumes 33% of final energy and produces 24% of total CO_2 emissions, *[5]*. Road transport holds the biggest share of the modes of transport and consequently consumes 83% of transport energy and produces 93% of the CO_2 emissions, *[6]*. With the aim of achieving a 60% CO_2 reduction by 2050 (compared with 1990), Europe will need to reduce its oil consumption by around 70%, *[7]*, *[8]*. The transport sector is currently 96% oil dependent, which is unsustainable, *[9].*

The majority of transport-related activities occur in cities, where passenger cars contribute more than 60% to the total transport energy consumption and emissions, *[10]*. Commercial vehicles contribute to about 19% of energy use and 21% of CO_2 emissions, *[11]*. In the field of urban passenger mobility, many policies and measures have been proposed and implemented (public transport, electric vehicles, car sharing and carpooling, cycling and walking, etc.), but urban freight has been neglected for decades. Consequently, this has resulted in an increasing share of energy consumption and emissions of freight vehicles in cities.

Urban freight deliveries are nowadays also confronted with requests for just-in-time deliveries and e-commerce, which results in high fragmentation of urban freight demand and supply, *[12]–[14]*. Many cities are consequently facing an increasing number of poorly utilized urban freight transport trips, which decreases energy efficiency and increases pollution, *[15]*, *[16]*. Empirical studies of urban freight deliveries show that the average load factor of urban freight vehicles is only at 30-40% *[1]*, *[17]* and more than 20% of vehicles drive empty, *[18]*.

The problem of the "last mile" is perceived as the most inefficient part of the supply chain. The final part of shipment typically involves multiple stops with small numbers and sizes of parcels, *[19]*. Last mile delivery is considered to be the most expensive (it represents from up to 53% of delivery costs, as seen in Figure 2) and the most time-consuming part of the shipping process (limited access to customers and congestion in cities), *[20]*.

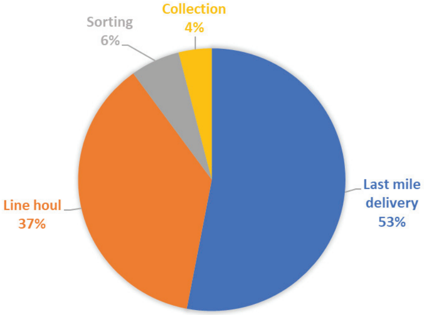

***Figure 2:** Share of delivery costs by part of the journey,* [19]

With increasing urban population and economic activities in cities, the efficiency of last mile delivery needs to be appropriately addressed to influence improvement in energy savings and a decrease in pollution, *[21]*. Solutions for efficient urban freight movements are sought from both the practical and the theoretical points of view.

2 SOLUTIONS FOR ENERGY EFFICIENT URBAN DELIVERIES

Cities are most often addressing the urban freight delivery problems by implementing different kinds of restrictive policy measures, with the main aim of mitigating the negative effects of deliveries (e.g., ban for heavy-duty vehicles, low emission zones, implementing access time windows, congestion charging, etc.), *[22]–[27]*. These kinds of measures are indeed contributing to decreasing the number of delivery vehicles and their negative effects in city centres, but at the same time negatively influencing the efficiency of last mile delivery (costs and time). The solution that is most convenient for the city authorities is in many cases hindering the efficiency of city logistics services.

When customers cannot be reached directly by regular delivery vehicles, the usage of Urban Consolidation Centres (UCC), where transhipment of parcels from large trucks to smaller and environmentally friendly vehicles, is suggested. Experiences from different cities revealed that only a small part of users decide to opt for UCC, because it results in additional costs and time spent for last mile delivery, *[28].*

The other solution for the last mile delivery is the usage of (un)loading bays, which are dedicated to transhipment of parcels and parking of delivery vehicles near customers during last mile delivery operations. Loading bays are most often located on the border of restricted areas within the cities. The last part of the delivery, from the loading bay to the customer, is predominantly done on foot or by trolley, *[29]*.

Loading bays can be used as a stand-alone solution or can be integrated with Urban Consolidation Centres, as presented in Figure 3.

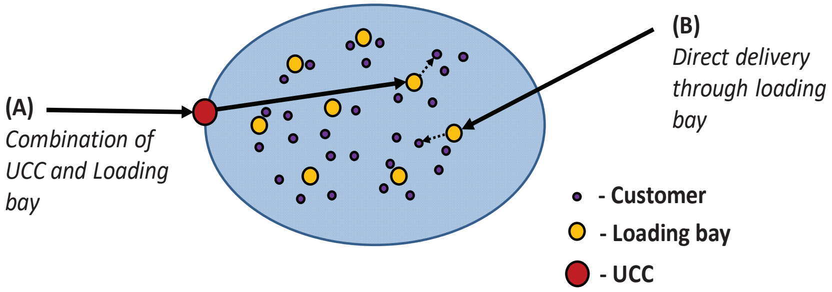

Figure 3: *Schematic presentation of direct delivery through loading bay and delivery in combination with UCC*

Urban areas are very often confronted with scattered loading bays. Cities are, therefore, attempting to identify the optimal number and position of loading bays to fulfil the requirements of the customers. Loading bays are also often occupied, sometimes by other delivery vehicles, but in most cases illegally from individual users, *[30]*, *[31]*. Delivery vehicles that are not able to find an available loading bay are forced to double park or cruise for parking (as seen in Figure 4), which is time-consuming and contributes significantly to the reduction of available road capacity and urban traffic congestion, *[32]*, *[33]*.

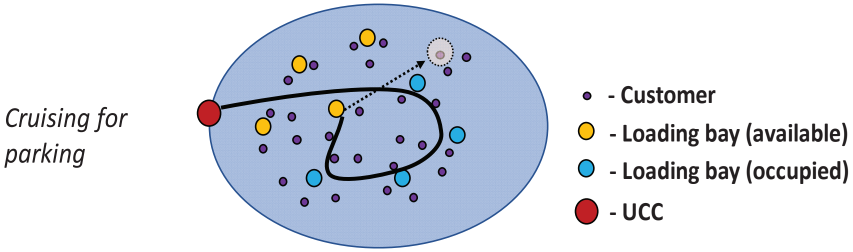

Figure 4: *Cruising for parking in the case of occupied loading bays*

To cope with the mentioned problems, cities are attempting to find delivery area management solutions. Different loading bay management solutions have been recently tested in several European cities. Lyon provided options to reserve a loading bay 24 hours in advance, which led to more efficient trips and routes in the city and resulted in a 40% reduction in double parking, as well as reduced congestion and pollution in the city centre, *[30]*. Vienna experimented with different management methods and technological solutions for the efficient and effective monitoring of the occupancy of loading bays with the aim of keeping loading bays at maximum availability and reducing impacts on traffic caused by the loading activities, *[34].* Lisbon adopted parking meters for loading/unloading operations and vehicle detection sensors installed on the ground of loading bays. This resulted with a reduced number of parking infractions, the reduced average duration of freight operations, and increased transport operators' and shopkeepers' satisfaction, *[35]*.

Possible approaches have been studied by Patier et al., *[36]*, highlighting the importance of the information system (or device) to inform all users of the occupancy of relevant loading bays. McLeod and Cherrett, *[37]*, investigated the impact of advanced booking of loading bays and observed the high level of sensitivity to early or late arrivals. In that case, the capacity of the system drops considerably. Based on that, they suggest opting for more dynamic loading bay reservation systems.

3 OPTIMIZATION OF LOADING BAYS FOR EFFICIENT DELIVERY

3.1 The algorithm and the model

An algorithm and model for the dynamic management of loading bays for efficient urban freight deliveries was developed recently by Letnik et al., *[26].* The algorithm is briefly presented next (see Figure 5).

Generally, the last mile delivery problem can be divided into two sub-problems: the delivery of goods from outside the city to the loading bay; and the delivery of goods from the loading bay to the customer. The latter aims to select the most appropriate loading bay and the vehicle path, considering a predefined set of loading bays and dynamically changing traffic conditions. The most appropriate loading bay is in the model determined via fuzzy clustering algorithm (FCM). In reality, the loading bay is chosen according to two different approximation methods.

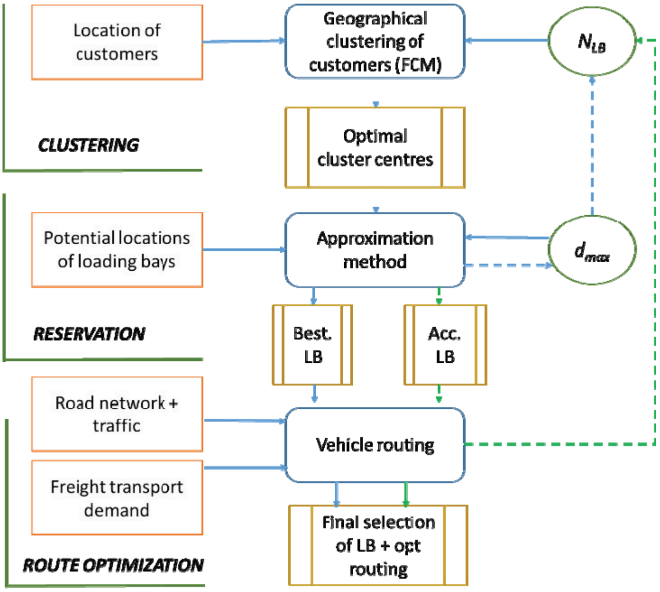

Figure 5: *The architecture of the proposed algorithm*

In the first approximation method, only the best potential loading bay (LB) (the closest to the cluster centre) is taken as an option. In the second approximation method, a set of acceptable LBs are considered. In both cases, čoading bays are considered only if the constraint of (predefined) maximal allowed walking distance from the LB to the customer is fulfilled.

The FCM procedure was used in the model because it permits the overlapping of clusters of customers and offers a more flexible selection of LBs. The clustering procedure searches for a maximum acceptable (walking) distance from the LB to the customer.

The routing is performed based on the Dijkstra algorithm, comparing 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. The routing algorithm also has the function of keeping vehicles outside the city in the case and until all acceptable LBs are occupied.

As seen from Figure 5, the location of customers (geographical coordinates) and a predefined number of LBs (N_{LB}) are two main elements needed for the 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 and acceptable LBs produced by approximation methods are determined according to the potential location of LBs and the value of d_{max}. If approximation methods do not result in finding an LB for all customers, then the d_{max} is increased, and clustering the algorithm runs again.

Vehicle routing aims to find the shortest possible path from outside the city to the LB, which is 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 in the shortest and fastest path and selects this LB as optimal.

The environmental performance of the system is measured in travel times, travel distances, CO_2 emissions, and fuel consumption. Our calculation considers deliveries performed with an average light commercial vehicle (category N1 - up to 3.5 tons) with a diesel engine. In urban areas, this kind of vehicle consumes on average 11.4 l of diesel per 100 km, which results approximately with 300 g/km CO_2 (taking into consideration conversion factor of 1 l/100km = 26.5 g/km CO_2), *[38]*.

3.2 Case study and results

The model has been applied to a real case study of the historical city centre of Lucca in Italy. The city of Lucca is one of the most advanced historical cities with regard to the application of city logistics policies and measures. Consequently, many data have been available, which presents a good basis for modelling purposes and testing of the proposed model. A more detailed elaboration of the model and the case study can be found in Letnik et al., *[29]*.

Access to the city centre is restricted with a Limited Traffic Zone (LTZ), and the level of restriction differs with different periods of the day. The number of customers located in the city centre is 1,161, the average number of daily deliveries is 1,272, and the number of commercial vehicles entering the city centre is 1,058, *[39]*. 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 city centre.

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%, *[39]*. We have decided to simulate only these three periods because in these periods different access restrictions apply, which also results in the availability of a different number of LBs (some locations 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 results in optimal LB assignment and routing. It is presented with the following schematic (Figure 6).

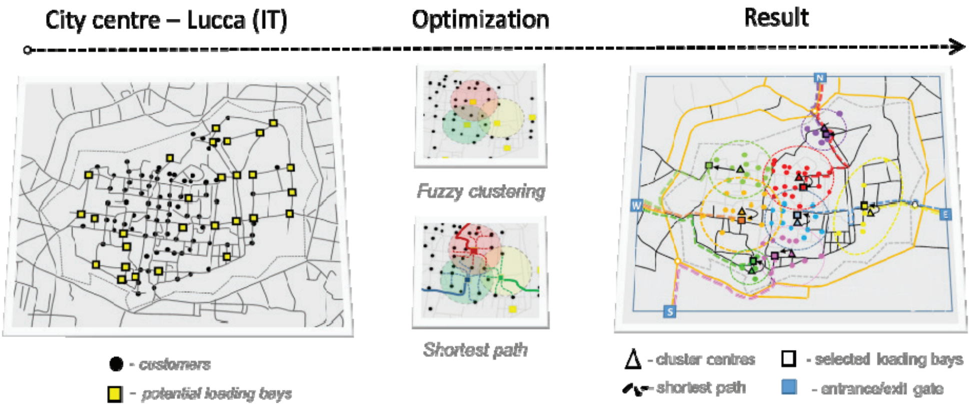

Figure 6: *Schematic presentation of the model application*

As seen from the Figure 6, we first identified the location of customers and potential location of loading bays (physical places in the city where loading bays can be placed and reached with delivery vehicles). The FCM algorithm was used to create clusters of customers with cluster centres, which represent the most optimal positions of loading bays. With an approximation approach, considering maximal allowed walking distance, each cluster of customers has been assigned with a potential set of loading bays. In the final step, a routing algorithm was used to calculate all the possible options of entering the city centre and reaching potential loading bays and, finally, to select the best possible loading bay and define the best possible vehicle path.

Several simulations of the algorithm result in significant savings in comparison to the existing scenario (direct delivery to each customer, without using LBs and without using the routing algorithm). In Table 1, total savings in terms of total travel time, driven distances, emissions of CO_2 and consumed fuel are reported, in terms of percentages, daily and yearly values. Total daily values are calculated according to the number of daily trips performed in each scenario (A=291, B=315, C=170). Total yearly values are calculated for 250 working days per year.

As seen from Table 1, daily savings altogether are: 147 hours of travel time, 3,021 km of distance travelled by freight vehicles, 906.2 kg of CO_2 emissions and 344 litres of diesel fuel, when the first approximation method is applied; and 170 hours of travel time, 3,489 km, 1,046.7 kg of CO_2 emissions and 398 l of diesel fuel in the case of the second approximation method. This account, on a yearly basis, for: 36,739 hours of travel time, 755,145 km, 227 tons of CO_2 emissions and 86,087 litres of diesel fuel, when the first approximation method is applied; and 42,559 hours of travel time, 872,273 km, 262 tons of CO_2 emissions and 99,439 litres of diesel fuel, in the case of the second approximation method.

***Table 1:** Total daily and yearly savings in case of using the first and the second approximation method (for all three periods of the day)*

TOTAL SAVINGS		1st approximation method	2nd approximation method
Total travel time	*h/day*	147.0	170.2
	h/year	36,739	42,559
Total distance	*km/day*	3,021	3,489
	km/year	755,145	872,273
Total Co2	*kg/day*	906.2	1,046.7
	tons/year	227	262
Total fuel consumption	*litre/day*	344	398
	litre/year	86,087	99,439

Additionally, the two compared approximation methods result in different performance in walking distances of the deliverer (from loading bays to customers) and the waiting time of the delivery vehicle before entering the city centre. In the case of the first approximation method (only the best possible loading bay - the closest to the cluster centre is selected), the average walking distances are only at about 70 metres, but vehicles must wait outside the city centre for approximately 30 minutes on average. If the second approximation method is used (the algorithm chooses from among all the acceptable options of feasible loading bays, not only the closest one), the average walking distance is around 300 metres, but vehicles almost never wait outside the city before performing the deliveries.

The results clearly indicate the need to consider the dynamic management of loading bays for urban freight deliveries as one of the most promising measures for achieving more sustainable and energy efficient cities.

4 CONCLUSIONS

The optimization of urban freight deliveries, based on the optimal assignment of loading bays and optimal vehicle routing, can result in considerable savings of travel time, travel distance, fuel consumption, and CO_2 emissions. Energy savings are mainly related to the decrease of driven distances, mostly caused by increasing the walking part of the delivery. However, more critical energy savings are gained by optimal routing and selection of the most optimal entrance/exit gate for serving a particular customer located in the city centre.

The results considered in this paper are based on the assumption of a single delivery for each instance (i.e., the delivery vehicle serves only one customer at the time). For the future work, multiple deliveries should be considered (i.e., serving several customers during one delivery operation). In this case, the vehicle routing will not be limited to the shortest path but will search for the optimal combination of loading bays and entrance/exit gate for serving several customers during one vehicle trip.

References

[1] **R. Bozzo, A. Conca, and F. Marangon:** *Decision Support System for City Logistics: Literature Review, and Guidelines for an Ex-ante Model*, Transp. Res. Procedia, Vol. 3, pp. 518–527, 2014

[2] **P. Centobelli, R. Cerchione, and E. Esposito:** *Environmental Sustainability and Energy-Efficient Supply Chain Management: A Review of Research Trends and Proposed Guidelines*, Energies, Vol. 11, no. 2, p. 275, 2018

[3] **S. Seme, K. Sredenšek, Z. Praunseis, B. Štumberger, and M. Hadžiselimović:** *Optimal price of electricity of solar power plants and small hydro power plants – Technical and economical part of investments*, Energy, Vol. 157, pp. 87–95, 2018

[4] **B. Xu and B. Lin:** *Differences in regional emissions in China's transport sector: Determinants and reduction strategies*, Energy, Vol. 95, pp. 459–470, 2016

[5] *Consumption of energy*, EUROSTAT - Statistics Explained. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy. [Accessed: 30-Aug-2018]

[6] **D. Huggins:** *Panorama of transport*. Eurostat, European Commision, 2009

[7] **A. G. Olabi:** *Energy quadrilemma and the future of renewable energy*, Energy, vol. 108, pp. 1–6, 2016

[8] **F. Ruzzenenti and R. Basosi:** *Modelling the rebound effect with network theory: An insight into the European freight transport sector*, Energy, Vol. 118, pp. 272–283, 2017

[9] *Transport*, European Environment Agency. [Online]. Available: https://www.eea.europa.eu/themes/transport/intro. [Accessed: 30-Aug-2018]

[10] *Reducing CO2 emissions from passenger cars*, European Comission, 2017. [Online]. Available: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en. [Accessed: 02-Oct-2017]

[11] **A. Nuzzolo, A. Comi, A. Ibeas, and J. L. Moura:** *Urban freight transport and city logistics policies: Indications from Rome, Barcelona, and Santander*, Int. J. Sustain. Transp., Vol. 10, no. 6, pp. 552–566, 2016

[12] **E. Morganti, L. Dablanc, and F. Fortin:** *Final deliveries for online shopping: The deployment of pickup point networks in urban and suburban areas*, Res. Transp. Bus. Manag., Vol. 11, 2014

[13] **J. Olsson and J. Woxenius:** *Localisation of freight consolidation centres serving small road hauliers in a wider urban area: barriers for more efficient freight deliveries in Gothenburg*, J. Transp. Geogr., Vol. 34, pp. 25–33, 2014

[14] **S. Tadić, S. Zečević, and M. Krstić:** *City Logistics – Status and Trends*, Int. J. Traffic Transp. Eng., Vol. 5, no. 3, pp. 319–343, 2015

[15] MDS Transmodal Limited, *Study on Urban Freight Transport*, *DG MOVE*, 2012

[16] **S. Iwan:** *Adaptative Approach to Implementing Good Practices to Support Environmentally Friendly Urban Freight Transport Management*, Procedia - Soc. Behav. Sci., Vol. 151, pp. 70–86, 2014

[17] **A. Domínguez, J. Holguín-Veras, Á. Ibeas, and L. dell'Olio:** *Receivers' Response to New Urban Freight Policies*, Procedia - Soc. Behav. Sci., Vol. 54, pp. 886–896, 2012

[18] **M. Tozzi, M. V. Corazza, and A. Musso:** *Urban goods movements in a sensitive context: The case of Parma*, Res. Transp. Bus. Manag., Vol. 11, pp. 134–141, 2014

[19] **S. Dolan:** *The challenges of last mile logistics & delivery technology solutions*, Business Insider, 2018. [Online]. Available: https://www.businessinsider.com/last-mile-delivery-shipping-explained

[20] **M. Roca-Riu and M. Estrada:** *An Evaluation of Urban Consolidation Centers Through Logistics Systems Analysis in Circumstances Where Companies have Equal Market Shares*, Procedia - Soc. Behav. Sci., Vol. 39, pp. 796–806, 2012

[21] **T. Letnik, M. Marksel, G. Luppino, A. Bardi, and S. Božičnik:** *Review of policies and measures for sustainable and energy efficient urban transport*, Energy, Vol. 163, pp. 245–257, 2018

[22] **H. J. Quak and M. (René) B. M. de Koster:** *Delivering Goods in Urban Areas: How to Deal with Urban Policy Restrictions and the Environment*, Transp. Sci., Vol. 43, no. 2, pp. 211–227, 2009

[23] **F. Russo and A. Comi:** *Measures for Sustainable Freight Transportation at Urban Scale: Expected Goals and Tested Results in Europe*, J. Urban Plan. Dev., Vol. 137, no. 2, pp. 142–152, 2011

[24] **J. Holguín-veras and I. Sánchez-díaz:** *Freight Demand Management and the Potential of Receiver-Led Consolidation programs*, Transp. Res. Part A: Policy and Practice, Vol. 84, pp. 109–130, 2016

[25] **H. Buldeo Rai, T. van Lier, D. Meers, and C. Macharis:** *Improving urban freight transport sustainability: Policy assessment framework and case study*, Res. Transp. Econ., 2017

[26] **E. Marcucci, V. Gatta, M. Marciani, and P. Cossu:** *Measuring the effects of an urban freight policy package defined via a collaborative governance model*, Res. Transp. Econ., Vol. 65, pp. 3–9, 2017

[27] **J. Fu and E. Jenelius:** T*ransport efficiency of off-peak urban goods deliveries: A Stockholm pilot study*, Case Stud. Transp. Policy, 2018

[28] **T. G. Crainic, N. Ricciardi, and G. Storchi:** *Models for Evaluating and Planning City Logistics Systems*, Transp. Sci., Vol. 43, no. 4, pp. 432–454, 2009

[29] **T. Letnik, A. Farina, M. Mencinger, M. Lupi, and S. Božičnik**: *Dynamic management of loading bays for energy efficient urban freight deliveries*, Energy, Vol. 159, pp. 916–928, 2018

[30] **M. Browne, J. Allen, T. Nemoto, D. Patier, and J. Visser:** *Reducing Social and Environmental Impacts of Urban Freight Transport: A Review of Some Major Cities*, Procedia - Soc. Behav. Sci., Vol. 39, pp. 19–33, 2012

[31] **J. Muñuzuri, M. Cuberos, F. Abaurrea, and A. Escudero:** *Improving the design of urban loading zone systems*, J. Transp. Geogr., Vol. 59, pp. 1–13, 2017

[32] **J. de A. e Silva and A. Alho:** *Using Structural Equations Modelling to explore perceived urban freight deliveries parking issues*, Urbe 2015, pp. 1–20, 2015

[33] **F. Russo and A. Comi:** *City Characteristics and Urban Goods Movements: A Way to Environmental Transportation System in a Sustainable City*, Procedia - Soc. Behav. Sci., Vol. 39, pp. 61–73, 2012

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

[35] **T. Cherrett, J. Allen, F. McLeod, S. Maynard, A. Hickford, and M. Browne:** *Understanding urban freight activity – key issues for freight planning*, J. Transp. Geogr., Vol. 24, pp. 22–32, 2012

[36] **D. Patier, B. David, R. Chalon, and V. Deslandres:** *A New Concept for Urban Logistics Delivery Area Booking*, Procedia - Soc. Behav. Sci., Vol. 125, pp. 99–110, 2014

[37] **F. McLeod and T. Cherrett:** L*oading bay booking and control for urban freight*, Int. J. Logist. Res. Appl., Vol. 14, pp. 385–397, 2011

[38] **G. Mellios, S. Hausberger, M. Keller, C. Samaras, L. Ntziachristos, S. Hausberger, C. Samaras, G. Mellios, and L. Nziachristos:** *Parameterisation of fuel consumption and CO2 emissions of passenger cars and light commercial vehicles for modelling purposes*. 2011

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