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Integrated urban freight logistics combining passenger and freight flows – mathematical model proposal

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Abstract

The aim of this research is to propose an urban logistics distribution service which benefits from the already installed passenger transport network. This service is based upon the concept of integration of the existing passenger transport network with the urban freight process. The aim is to reduce the number of fossil combustion powered commercial vehicles traveling within city boundaries, solely for goods transportation, thus contributing to reduce negative effects of urban logistics activities, namely pollution, noise, traffic congestion and accidents. Also, integrating goods and passenger flows will promote higher efficiency rates for the passenger transport network and enhance living conditions within major urban centers. A mathematical model for the operational planning of the proposed urban logistics distribution service is proposed. This model consists of assigning origins loads (or requests) to inbound hubs (bus operator centers), transferring the inbound hubs loads to a bus service, and transferring the bus loads to bus stops, to be collected by micro-logistics operators operating environmentally friendly vehicle fleets. The objective is to minimize the total service time while assuring services synchronization along the network and balancing the loads with the system capacities.

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Keywords: City Logistics; Urban Logistics; Mathematical Model; Integrated Passenger and Freight Transportation; Operational Planning

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1. Introduction

Urban logistics (UL) or city logistics is an important subject of urban mobility concerned with the activities of delivering and collecting goods in a town and city centers. These activities typically entail the processes of transportation, handling and storage of goods, the management of inventory, waste and returns as well as home delivery services. Several authors highlight that UL does not received so far the attention it deserves (see as an example European Commission (2013). Only in the recent past, there seems to be an increasing interest of the community in this problem, as can be noticed by the several recent books dedicated to the topic (see, as examples, Gonzalez-Feliu *et al.* (2014) and Taniguchi *et al.* (2014)).

Although urban logistics constitute a relatively small share of urban traffic (Macário e*t al.*, 2011), it makes a major contribution to the success of cities and is essential to the urban economy . Furthermore, the demand for UL, namely the increase of cities' supply flows, is expected to increase in the future, due to the increase of urban population as well as due to the new on-line trading trends. On the other hand, the accessibility to urban areas is more and more constrained, atrophied by harder regulatory frames (access hours, conditions of delivery stops), and, in addition, more and more uncertain due to the congestions of the road network (Gonzalez-Feliu *et al.*, 2014).

In this paper an urban freight distribution service is proposed as well as a mathematical model for a medium to short term planning problem arising. At this level the major concern is to establish a distribution plan assuring that all the resources of the network are well managed and controlled, while satisfying the customers' demands within a given time window and with the lowest possible nuisances to the city life. In that respect, we will challenge the following planning problems (in the context of the integration of urban passenger and freight flows): (i) the freight network flow assignment problem; (ii) the vehicle and logistics infrastructures loads and capacity balance problem; and iii) the spatial and temporal synchronization requirements between vehicles along the urban network.

The aim of this paper is twofold: i) to propose and characterize an innovative urban freight distribution system that integrates urban passenger and urban freight flows, and ii) to develop an optimization model for the operational management of associated logistics and transportation activities. Specifically, for each load to be delivered we will tackle the following decisions: 1) assignment of the load to a bus operator center; assignment of the load to a bus route; and 3) assignment of the load to a bus stop, to be collected and delivered by micro-logistics operator(s), considering system capacity and synchronization requirements involved, while minimizing the service time.

The remaining of this paper is organized as follows. In Section 2 a literature review is presented. Section 3 describes the integrated urban logistics service proposed. In Section 4 a mathematical model, to support the decision making process of an operational planning problem emerging in the context of the new service, is elaborated. Section 5 is dedicated to the evaluation of the mathematical model through a set of generated instances. An illustrative example is also presented in this section. The paper concludes with Section 6 where the main conclusions of this research are drawn.

2. Literature Review

Traditionally, in theory and in practice, the flows of people and goods in the city have been treated separately, although both entities share the same road infrastructure and influence each other, being one of the main advantages resulting from the integration of the two types of flows the best use of available capacity. Also, combining people and freight flows creates attractive business opportunities because the same transportation needs can be met with fewer vehicles and drivers (Bektas *et al.*, 2017). Several authors discuss the benefits of this integration (Boudoin *et al.*, 2014; Macário *et al.*, 2011; and European Commission, 2013), although the literature in which it is properly studied is almost inexistent. Nonetheless, in the recent literature a new research stream is emerging in the field of UL, aiming to promote the integrated management of goods movements in urban centers in order to aggregate various agents and services and inciting the emergence of new forms of business to support an agile distribution (less average delivery volume and more frequency of delivery), using smaller and less polluting vehicles (e.g. bicycles) (Schliwa *et al.*, 2015). According to several authors (Bozzo *et al.*, 2014; Crainic *et al.*, 2009), it is necessary to provide urban freight transportation with "intelligence", with integrated services and more advanced specialized intermediary systems. However, the literature dealing with intelligent freight transportation systems (IFTS) in urban context with the aggregation of several agents, is scarce. The works from Ghilas *et al.* (2013); Li *et al.* (2014) and Masson *et al.* (2017) can therefore be considered pioneers in the subject, being all of them focused on the development of optimization models and methods to support decision making. Li *et al.* (2014) combine people and parcel flows using taxis, to assist the taxis routes' planning. The author's present mixed integer programming (MIP) formulations to static and dynamic planning scenarios, concluding that more computationally efficient algorithms are needed to solve realistic instances. More recently, Li *et al.* (2016) have proposed a variant of the problem addressed in Li *et al.* (2014), incorporating the uncertainty associated with transportation times and delivery locations. In this case, the authors present a two-stage mixed integer stochastic programming model, and an adaptive large neighborhood search algorithm. Ghilas *et al.* (2013) tackle the problem of scheduling a set of vehicles to serve requests such that a part of the journey can be carried out on a scheduled passenger transportation service, considering multi-modality of traditional passenger-oriented transportation modes, such as taxi, bus, train or tram. The authors model the problem as an arc-based MIP formulation considering passenger and packages pick-up and delivery requests. On the other hand, Masson *et al.* (2017), based on a case study in the French city of La Rochelle, propose the integration of passenger flows and freight flows into the problem of optimizing the daily distribution of urban goods in business-to-business (B2B) contexts, through the use in an integrated way of a homogeneous bus fleet with a homogeneous environmentally friendly city freighters fleet, having a capacity of one roll container, to ensure the last stage of the process. Another contribution to the field is the work from Strale (2014) that evaluates the potential use of urban light rail for freight distribution, grounded on the Brussels case.

3. Integrated Urban Logistics Service Description

Nowadays, the majority of the cargo distribution in the cities is performed by private companies, typically urban logistics operators or the suppliers of the goods, using a dedicated fuel based fleet of vehicles. The problem is characterized by a huge number of small orders (in volume and weight) to be delivered to a huge number of customers and retailers, disperse in the city, facing a huge challenge to optimize the daily loads in order to avoid empty or partial km runs. Furthermore, there are typically access constraints in some streets of the city creating restrictions on the type of vehicles that can be used. On the other side, the passenger transportation in a city is mainly assured by a dedicated, public or private, network of buses, taxis, trams and metro, as well as by privately owned car users. During the day the passenger demands vary significantly resulting in a challenge to the management of the fleet and drivers and in poor performance in terms of the capacity utilization. The integration of both flows allows using the spare capacity of city passenger network to carry some types of cargo (e.g. parcel distribution) to the city core. The integration of the two types of distribution flows is quite common in the long-haul distribution and has proved results. However, in the first and last mile delivery it is almost inexistent, making it an interesting research topic. We believe that integrating passenger flows with freight flows, coupled with the use of environmentally friendly vehicle fleets to ensure the last mile delivery, as well as the use of integrated and intelligent decision support, will have a positive impact on urban mobility.

In this work we propose the creation of a new business model for the distribution of goods in urban environments, which is labeled Integrated Urban Logistics Service (IULS), focusing on the use of the bus transportation infrastructure operating in the urban network and the use of environmentally friendly fleets, to ensure the last mile delivery of some types of goods. The new service is particularly suited to the delivery of parcels to shops, private customers or public or private entities.

The proposed business model could also use other means of city passenger's transportation in an isolated or integrated way. Obviously, the integration of several means of public transportation would enhance the system flexibility.

In order to ensure a service tailored to customer needs and to facilitate the decision-making process in the new business model, the main motivation of this research is the development of an intelligent decision support system (IDSS) that will allow the optimized management of transportation combining two or more modes of transportation and passenger and freight flows. The IDSS will allow the management of the logistics and transportation operations along the network in a coordinated and synchronized way, in space and time. This later aspect assumes a preponderant role in the freight loading, unloading and transfer points.

Since the city bus network operates on a fixed route system it cannot ensure the door-to-door delivery service. So, a door-to-door delivery service, using a fleet of environmentally friendly vehicles, will operate coordinated and synchronized with the bus network.

In general terms, the operation of this new urban logistics distribution service will be ensured through the transshipment or transfer of the goods in a set of strategic points in the network, in two different stages, between its point of origin (usually a distribution center or a factory located outside the city) and its final destination (usually a location chosen by a private customer, a retailer or any other public or private entity).

For each order, after a request for service, from a customer who intends to send goods to one or more locations within the city, the service provider (or the owner of the IULS system) shall affect the goods to a bus operator hub, defining among other things, the bus operator hub where the goods are to be delivered (from a set of locations strategically located in locations on the outskirts of the city or in a limited set of locations in the city, for example at the terminals of the passenger transport operators), thus occurring the first transfer of the goods. In the next stage, the goods are transported by the passenger transport operator into the city to a location as close as possible to its final destination (at a stopping point of the transportation operator – bus stop) and collected by micro-logistics operator(s) (operating an environmentally friendly fleet), who shall ensure the goods delivery from that location to their final destination. This corresponds to the second transfer of the goods. In the last stage of the goods journey, their delivery to the several final customers will be integrated into the daily operations of the micro-logistics operator(s), and so, they can be delivered right after their collection or not, depending on the operational management that is taken by the micro-logistics operator. Nonetheless, the micro-logistics operator is responsible for ensuring compliance with the time windows agreed with the final customer. These decisions will help the IULS provider to set the business activities that are triggered to provide a response to the customer request (or order), by accepting or rejecting the order (depending on the network loads *vs* available capacities), and setting/agreeing the delivery date (as a time window). The customer interacts with the IULS provider through an App owned by the IULS provider.

Upon the customer acceptance of the conditions and terms of the IULS provider the customer places the order using the App. Afterwards, the IULS provider sends a confirmation to the customers and interacts with the bus operator(s) and with the micro logistics operator(s) to feed them with all the required information about the service. We note that all the interactions amongst the logistics network actors occur through the IULS App. As an example some relevant information to the micro logistics operator(s) includes the bus stops were the request (or orders) will be unloaded, estimated arriving times of orders at the bus stops, orders characteristics, orders final destinations and orders time windows.

In order to minimize cargo handling operations during the distribution process, all goods at a given bus operator center, flowing through a given bus service to a given bus stop, should be properly protected and packed before being dispatched. It is assumed that the same type of container is used along the logistics network and that it is suitable to all the vehicles that will transport them as well as to the handling process. Moreover, the freight load cannot be partitioned, i.e., the demand associated to each request is fully collected at one bus operator center, is transported by one bus service, then is fully dropped at one bus stop and fully collected by the last mile delivery operator (or micro logistics operator). Nonetheless, each bus service may transport several different requests/types of goods to different customer locations. Also, the goods can only be loaded to a bus service at bus operator centers and once associated to a bus service can only be unloaded at bus stops. None loading operations can occur at the bus stops.

The IULS system is operated on an on-demand basis. Typically the service times required by the customers will fall within a short time horizon, so the IULS system should be optimized within short intervals of time, ideally in real time management.

The logistics network is composed by a set of suppliers' locations, a set of bus operator centers, a set of bus services, a set of bus stops, and a set of customer locations. In the following paragraphs some details about each entity are presented.

Customer

The customers using IULS can be any type of entity that needs to send or receive goods in a location within a city. Typically, the customer will be a logistics service provider or a supplier that needs to deliver the goods to a customer or set of customers located within the city. Nonetheless, the customer can also be a retailer, a private person, or any kind of service entity located in a city. Customers place requests, being each request characterized by an origin location (or supplier location), a destination location, a demand (as a number of equal sized containers), a time window and a release time. The customer is responsible for ensuring the delivery of the goods at a specified bus operator center. Estimates of the travel times between the origin location of the goods and the bus operator centers are known in advance.

Bus operator centers

The bus operator centers belong to the bus service routes. Their main activities are concerned with the collecting of the goods delivered to them by the suppliers; and to the sorting and dispatching of the goods by bus service. They can be the starting point of a bus route, the finishing point of a bus route or a passenger transshipment point. It is assumed that none goods can be transshipped between bus operator centers. Each bus operator center is characterized by a capacity (in terms of the number of containers it can handle per unit of time) and by the minimum time each request needs to stay there in order to ensure the completion of the required activities at the bus operator center.

Bus services

A bus service is defined by a bus line, a bus operating this bus line and a fixed schedule and route, known in advance. Thus, the estimated starting or arriving times of the bus service to a bus operator center and the travel times between a bus operator center and a bus stop are known. Moreover, each bus service has also a limited capacity measured as the number of containers that it can transport, taking into account both the bus unfilled space and a maximum level of deterioration of the quality of service offered to passengers.

Bus stops

Each bus stop is characterized by a service time corresponding to the time needed to unload the goods from the bus and load them in the micro logistics operator vehicle(s), and by a capacity expressed as the maximum number of containers that can be unloaded at a given bus stop so as to not compromise the passenger's service quality. At the bus stops the synchronization requirements between the bus services and the micro logistics operator are particularly relevant. When the bus arrives to the bus stop the micro logistics operator should be there. Otherwise, the goods cannot be unloaded, unless they can be left protected (e.g. be placed in a logistics box and afterwards be picked up by the micro logistics operator). In the vehicle routing literature the synchronization of vehicles means to couple the routes of two or more vehicles (Mankowska *et al.*, 2011). According to the same authors, the spatial dimension of the synchronization defines the location where vehicle synchronization can take place (at fixed points or at variable points) and the temporal dimension defines the order in which vehicles must visit a synchronization point (simultaneously or with a given precedence). In IULS the vehicles (bus and micro logistics vehicle) have to meet simultaneously at synchronization points, the bus stops, that are selected in the planning, making part of the decision process.

Micro logistics operator

The micro logistics operator is responsible for the multimodal connection that will occur at the bus stop, ensuring the transportation of the order from the bus stop to the final customer within the agreed customer time window. It is assumed that the micro logistics operator does not operate exclusively to the IULS, incorporating the IULS orders in its daily operations. So, a service time between the bus stop and the customer location must be considered. This time represents the agreed time, between the IULS owner and the micro logistics operator to the goods delivery to its final destination.

4. Mixed Integer Programming Model

In this section we model the assignment and synchronization problem arising in the operational planning of IULS as a mixed integer programming model. Next we formally present the proposed MIP model. Consider the following sets, parameters and decision variables:

Sets:

K - set of requests
T - set of bus operator centers
S - set of bus stops
P – set of bus services
$S(t)$ - set of bus services offered at bus operator centre t
$S(p)$ - set of bus stops of service p

Parameters:

D_k – demand associated to request k
$[E_k, L_k]$ – request k time window. E_k and L_k represent the earliest and latest delivery dates of request k, respectively
I_{pt} – bus service p start time at bus operator center t *or* arriving time of bus service p at bus operator centre t considering the bus service schedule
L_T_{kt} – time spent by request k at bus operator center t
L_S_{ks} – time spent by request k at bus stop s
L_A_{kt} – travel time between request k origin and bus operator center t
L_B_{ks} – micro logistics operator(s) service time (considering its service options) to deliver request k from bus stop s and customer location
L_TS_{pts} – bus service p travel time between the bus operator center t and bus stop s
R_k – request k release date
U_T_t – available capacity at bus operator center t
U_P_p – available capacity at bus service p
U_S_s – available capacity at bus stop s
M - a big number

Decision Variables:

X_{kt} – Binary variable that is equal to 1 if request k is assigned to bus operator center t and is equal to 0 otherwise
Y_{kp} - binary variable that is equal to 1 if request k is assigned to service p, *i.e.* if service p transports request k and is equal to 0 otherwise
Z_{kps} - binary variable that is equal to 1 if request k traveling in service p drops the bus at bus stop s and is equal to 0 otherwise
T_{kt} – request k departure time from bus operator center t
S_{ks} - request k departure time from bus stop s
U_k - request k arriving time at customer location

The operational planning problem described in Section 3 can then be modelled as:

$$\min \sum_{k\in K} U_k \tag{1}$$

subject to:

$$\sum_{t\in T} X_{kt} = 1, \forall k \in K \tag{2}$$

$$X_{kt} = \sum_{p\in S(t)} Y_{kp}, \forall t \in T, \forall k \in K \tag{3}$$

$$Y_{kp} = \sum_{s\in(p)} Z_{kps}, \forall k \in K, \forall p \in P \tag{4}$$

$$\sum_{k\in K} D_k \times X_{kt} \le U\_T_t, \forall t \in T \tag{5}$$

$$\sum_{k\in K} D_k \times Y_{kp} \le U\_P_p, \forall p \in P \tag{6}$$

$$\sum_{k\in K} D_k \times Z_{kps} \le U\_S_s, \forall p \in P, \forall s \in S(p) \tag{7}$$

$$T_{kt} \geq I_{pt} - M\left(1 - Y_{kp}\right), \forall k \in K, \forall t \in T, \forall p \in S(t) \tag{8}$$

$$I_{pt} \geq R_k + L\_A_{kt} + L\_T_{kt} - M\left(1 - Y_{kp}\right), \forall k \in K, \forall t \in T, \forall p \in S(t) \tag{9}$$

$$S_{ks} \geq T_{kt} + L\_TS_{pts} + L\_s_{ks} - M\left(1 - Z_{kps}\right), \forall k \in K, \forall t \in T, \forall p \in S(t), \forall s \in S(p) \tag{10}$$

$$U_k \geq S_{ks} + L\_B_{ks} - M\left(1 - Z_{kps}\right), \forall k \in K, \forall t \in T, \forall p \in S(t), \forall s \in S(p) \tag{11}$$

$$U_k \geq E_k, \forall k \in K \tag{12}$$

$$U_k \leq L_k, \forall k \in K \tag{13}$$

$$X_{kt}, Y_{kp}, Z_{kps} \in \{0,1\}, \forall k \in K, \forall t \in T, \forall p \in P, \forall s \in S \tag{14}$$

$$T_{kt}, S_{ks,}, U_k \geq 0, \forall k \in K, \forall t \in T, \forall s \in S \tag{15}$$

In the objective function, equation (1), the total customer's service time is minimized. The customer service time is measured as the time between the request origin location and the customer location, including handling and transportation times. Estimated requests' waiting times are included in the handling and transportation times. Constraints (2) force each request to be attributed to one and only one bus operator center, assuring that none load partitions will occur. Constraints (3) and (4) are the flow conservation constraints. Constraints (3) guarantees that if a given request is sent to a given bus operator center, then one bus service available at that bus operator center must be selected to transport that request, thus ensuring the request is expedited from the bus operator center. Furthermore, constraints (4) ensure that if a given request travels in a given bus service, then it has to be dropped off in a given bus stop belonging to the bus service route. Only one bus stop can be selected. The constraints sets (5), (6) and (7) are the capacity constraints. Constraints (5) establish an upper limit for the quantity of requests that can be sent to a given bus operator center so as to ensure that the bus operator center capacity per unit of time is respected. Constraints (6) also establish an upper limit for the total number of requests that can be assigned to a given bus service. Finally, constraints (7) establish an upper limit for the total number of requests from a given bus service that can be assigned to a given bus stop. The unit of time should be defined accordingly to the problem time horizon, i.e. to the time between optimizations. Constraints (8) to (11) model the time and synchronization constraints. Constraints (8) and constraints (9) establish the requests' departing times at the bus operator centers, synchronizing the requests availability at the bus operator center (considering their release dates, travel times from their origin to the bus operator center, as well as the required time to prepare the requests at bus operator centers) with the bus service. Constraints (10) coordinate the requests' departing time from the bus stops with their departing time from the bus operating center. They state that the requests' departing time from the bus stops should be equal to or greater than their departing time from the bus operator center, plus their travel time between the bus operator center and the bus stop and the time needed to unload them from the bus and load them in the micro logistics operator vehicle(s). Also, they force the synchronization between the bus service and the micro logistics operator. Constraints (11) coordinate the requests' arriving time to the customer with their departing time from the bus stop, by including the micro logistics operator service time. The sets of constraints (12) and (13) guarantee that the customer' time window is respected. Finally, constraints (14) are the binary constraints, forcing the decision variables to take binary values and constraints (15) are the non-negativity constraints.

5. MIP Model Evaluation

In this Section an illustrative example of application of the MIP model (presented in Section 4) to problem IULS (described in Section 3) is presented, as well as some computational tests.

Consider an example of problem IULS with three customers (1, 2 and 3), two bus operator centers (BusOperatorCenter1 and BusOperatorCenter2), four bus services (1 to 4) and five bus stops (1 to 5). Bus service 1 route is: BusOperatorCenter1 – bus stop 1 – bus stop 2 - BusOperatorCenter1; Bus service 2 route is: BusOperatorCenter1 – bus stop 1 – bus stop 2 – bus stop 3 – bus stop 4 – bus stop 5 – BusOperatorCenter1; Bus service 3 route is: BusOperatorCenter2 – bus stop 5 – bus stop 4 – bus stop 3 – BusOperatorCenter1 – bus stop 1 – bus stop 2 – BusOperatorCenter1; and Bus service 4 route is: BusOperatorCenter2 – bus stop 3 – bus stop 4 – bus stop 5 – BusOperatorCenter2). Moreover, all requests have a release data equal to zero and L_B is equal to 2 for all the combinations of requests/ bus stops. The remaining data associated with this example is presented in Table 1, Table 2, Table 3 and Table 4.

Table 1. Service time and capacity at bus stops.

		Bus stop				
	L_S:	1	2	3	4	5
Request	1	1	1	1	1	1
	2	5	5	5	5	5
	3	2	2	2	2	2
U_S		60	50	30	70	50

Table 2. Bus service start time and bus services capacity.

		Bus Operator Center		U_P
	I:	1	2	
Bus service	1	16	M	60
	2	10	M	100
	3	15	2	30
	4	M	12	70

Table 3. Requests data and time spent by request at bus operator centers.

		Request			U_T
		1	2	3	
Bus operator center	1	L_T 5 L_A 5	L_T 5 L_A 5	L_T 2 L_A 2	90
	2	L_T 5 L_A 7	L_T 5 L_A 5	L_T 2 L_A 3	60
Demand		10	30	60	
Earliest Delivery		20	15	15	
Latest Delivery		30	25	20	

Table 4. Travel times between bus operator centers and bus stops for each bus service.

		L_TS:	Bus stop				
		Bus service	1	2	3	4	5
Bus operator center	1	1	5	7	M	M	M
		2	5	7	10	15	18
		3	8	11	M	M	M
		4	M	M	M	M	M

	2	1	M	M	M	M	M
		2	M	M	M	M	M
		3	M	M	4	3	2
		4	M	M	8	10	14

The MIP model was implemented in IBM ILOG CPLEX Optimization Studio 12.8.0 (IBM Knowledge Center, 2018). The objective function value of the example is equal to 66 units of time. Request 1is sent from its origin to bus operator center 2. There, it will be loaded in bus service 4, departing at instant time 12. Afterwards, it will be dropped off at bus stop 3, departing from there to its final destination at instant time 21. Assuming that the micro logistics operator will fully use the service time, request 1 will reach its final destination at instant time 23. Request 2 and 3 use bus operator center 1 and bus service 2. Both requests depart from bus operator center 1 at instant time 10. Moreover, request 2 is left at bus stop 2, departing from there to its final destination at instant time 22. Also, request 3 is dropped off at bus stop 1, departing from there at instant time 17 and reaching its final destination at instant time 19. Request 2 arrives to customer at instant time 24.

In order to evaluate the MIP model a set of four instances were generated. These instances were adapted from the instances presented in Masson *et al.* (2017). A Surface Pro 4 Intel Core i5, processor 2.4 Ghz, 4 GB of RAM was used to perform the computational experiments. A summary of the instances characteristics is presented in Table 5 (columns 2 to 7), as well as the objective function value of the optimal solution (column 8) and the computational time to reach the optimal solution (column 9).

Table 5. Instances characteristics and computational results.

Instance	Min Dem.	Max Dem.	Avg Dem.	N.º Requests	N. Bus Services - N. Bus Stops	Time Window	Optimal Solution	Computational Time (seconds)
Inst. 1	10	50	32	50	10-6	2 hours	3674	56
Inst. 2	8	77	41	50	20-6	1 hour	3637	15
Inst. 3	10	30	21	100	20-6	2 hours	7272	302
Inst. 4	10	50	29,66	100	30-6	1 hour	7289	2152

Careful conclusions should be taken from the results analysis due to the instances set size. Nonetheless, the results show that the MIP model performance is sensitive to the instances characteristics. However, a higher number of instances should be created and tested in the future to reinforce the conclusions reached with this small data set.

6. Concluding Remarks

This work is intended to contribute to the identification and development of alternative solutions for freight distribution in urban areas with the aim to minimize its negative impacts. The central idea is to address the problem through the integration of flows of people and goods, in order to ensure a more efficient and environmental-friendly distribution process, using, whenever possible, the same transportation network. The urban logistics service presented in this paper requires a mindset shift of the key stakeholders, such as local authorities, city logistics operators, city collective passenger transport companies, and urban population. Nonetheless, we believe that the integration of passengers and freight flows, in conjunction with the exploitation of clean/low emission vehicle fleets, among other strategies, will have a positive impact in the city mobility. In this paper a Mixed Integer Programming model for the medium to short term planning of the urban logistics service proposed is developed and tested through a small data set. The MIP model addresses the problems of balancing the freight loads with the system' capacity, and synchronizing the distribution process along the urban network, while establishing the required time to service customers. In order to mimic reality some future improvements of the work are planned. A possible contribution would be the incorporation of uncertainty in some of the model parameters. Another contribution would be the consideration of pickup and delivery requests. Finally, a third contribution would be the modelling of the capacities in volume and the incorporation of different sized containers. Also, the MIP model needs to be further tested hopefully through a set of instances based on real data.

Despite the important theoretical contribution of this paper, there are limitations of the study that should be noted. First, application of the IULS system is lacking, for example trough a pilot test. Prior to its application, the technical logistics and transportation infrastructures requirements and system operational constraints should be subject to future research. Also, the robustness of the IULS system in real conditions should be tested. Moreover, the MIP model should be improved to tackle the practical issues raised on the real context as well as competitive algorithms developed. Hopefully, this paper opens the way for further development of the research.

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