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Improving the design of urban loading zone systems

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ABSTRACT

Despite the ubiquity of loading zones in most commercially dense streets of medium and large cities, there exists no generally acknowledged procedure to establish their number, location and management system. We propose a methodology divided in two steps, where the first one estimates the required number of loading zones on a given street and the second one locates them taking into account the delivery characteristics of the retail establishments they will be serving. The application of the methodology is tested in four streets in the Spanish city of Seville, following a retailer survey to collect all the relevant data. The results provided by the application in terms of number and location of loading zones are simulated together with other scenarios with different numbers of loading zones, and the outcomes are compared with the existing situation. The new methodology results in an improvement in the level of service provided with a similar – or smaller – number of loading zones, but most importantly causes a significant reduction in the distances between loading zone parking spaces and final destinations.

1. Introduction

All medium and large cities possess some type of infrastructure system aimed at facilitating the curbside operation of delivery vehicles. This infrastructure typically consists of specifically identified and reserved parking spaces called loading zones, usually subject to a series of restrictions of use in the form of availability periods, maximum standing time limits, etc. The local administration provides these loading zones normally in those areas where the affluence of delivery vehicles due to the density of retail commercial premises can represent an obstacle for traffic circulation if those vehicles cannot find a space available to park and deliver, always keeping in mind that the use of metered parking spaces is not an option in a sector with very low profit margins.

However, and despite the opposing facts that parking spaces are extremely scarce in the dense and commercial areas of cities and also that most cities consider this infrastructure as essential to ensure the smooth operation of delivery operations, there is not a clearly defined methodology to define, design and manage loading zones in urban areas, apart from the French guidelines published by CERTU (2009). Three different studies, published by Dezi et al. (2010) for the city of Bologna, Alho and De Abreu e Silva (2014) for the city of Lisbon, and Gardrat and Serouge (2016) for Bordeaux and Lyon contain in-depth assessments of urban loading zone systems, but without fully developing a methodology to assist local authorities in the provision of this type of spaces. As a result, decisions like how many should be provided, where should they be located or how should they be managed are taken by city administrators without a clear understanding of the needs, practices and restrictions of the different types of freight transport operating in the area. Loading zone systems are therefore sometimes insufficient and sometimes oversized and inefficient.

Furthermore, many urban freight reports focus their land use analyses at the zone level, evaluating different load-zone related options for given urban sectors (Woudsma et al. 2008; Alho and De Abreu e Silva, 2015). In our context, we nevertheless believe that decisions regarding the number, size and location of loading zones should be taken for individual streets, and not for sectors or areas. Loading zones on a given street, street segment or group of streets service those locations only, and the system designed for them may be entirely different from the one designed for another street two blocks down, with a different geometrical configuration, different types of commercial establishments, etc.

Seeking to refine and improve the CERTU guidelines, we have developed a procedure to design urban loading zone systems, including the determination of the number of loading zones required and the selection of the ideal location for those loading zones, which latter issue is in fact not addressed by CERTU. It is important to stress here that our focus is only on the design of traditional loading zone systems. Several innovative initiatives aimed at improving the management of these systems through the use of information technologies have been documented in the recent years (Roche-Cerasi 2012), but no urban area has so far undergone a generalized implementation of this type of initiatives.

In the following section we will describe our methodological proposal, divided into a quantification phase and a location-allocation process. The remaining of the paper will show the expected effects of introducing this methodology on a series of densely commercial streets,

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Table 1
Mathematical description of the three approaches considered to estimate the loading zone demand *D*.

a) Average demand	b) Peak demand	c) Coincident demand
$\frac{1}{T}\sum_j \sum_t f_{jt} \cdot e_j$	$\max_t \sum_j f_{jt} \cdot e_j$	$\sum_j \lceil f_j \rceil \cdot e_j$

analyzed through microscopic simulation. The results obtained will validate the methodology and show its potential as a decision-making tool to assist urban authorities when determining how many loading zones should be provided on a given street and where they should be located.

2. Methodological proposal

Our research objective was to develop an easily applicable methodology, which may be put into practice by local authorities interested in improving their public loading zone systems. We thus split the process into two stages, the first one aimed at determining the minimum number of loading zones required to service a given group of commercial establishments, and the second one seeking to determine the best location for those loading zones. The following sections provide the details of these two sequential stages.

2.1. Quantification problem

We consider a street, street segment or group of streets with M commercial establishments ($j = 1\ldots M$), each one of them receiving an average f_j deliveries per day and with an average delivery time equal to e_j for each delivery. In that case, the theoretical average daily loading zone demand (expressed in time units, usually

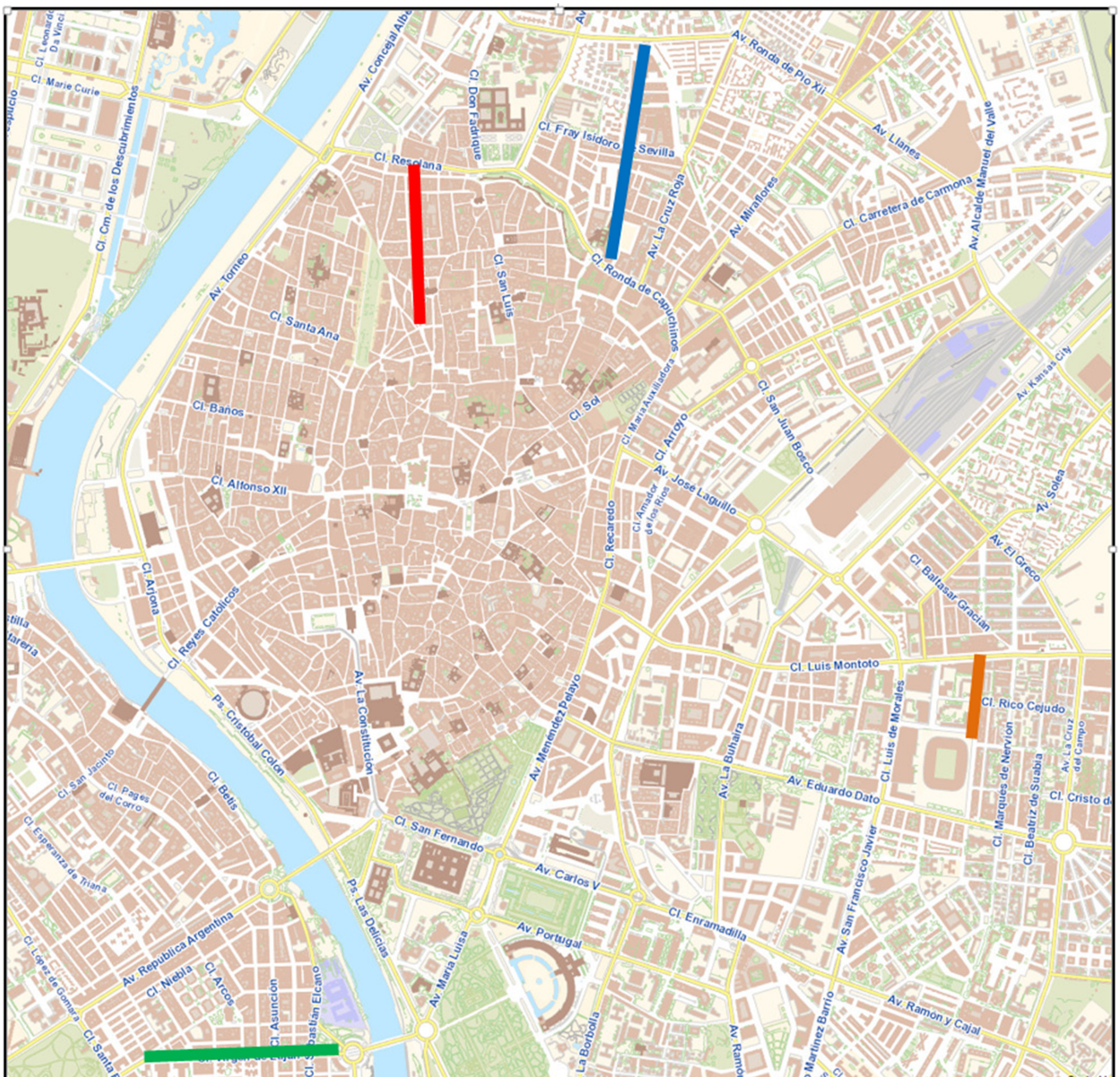

Fig. 1. Location of the analyzed streets in the city of Seville: Feria (red), León XIII (blue), José Luis de Casso (brown) and Virgen de Luján (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

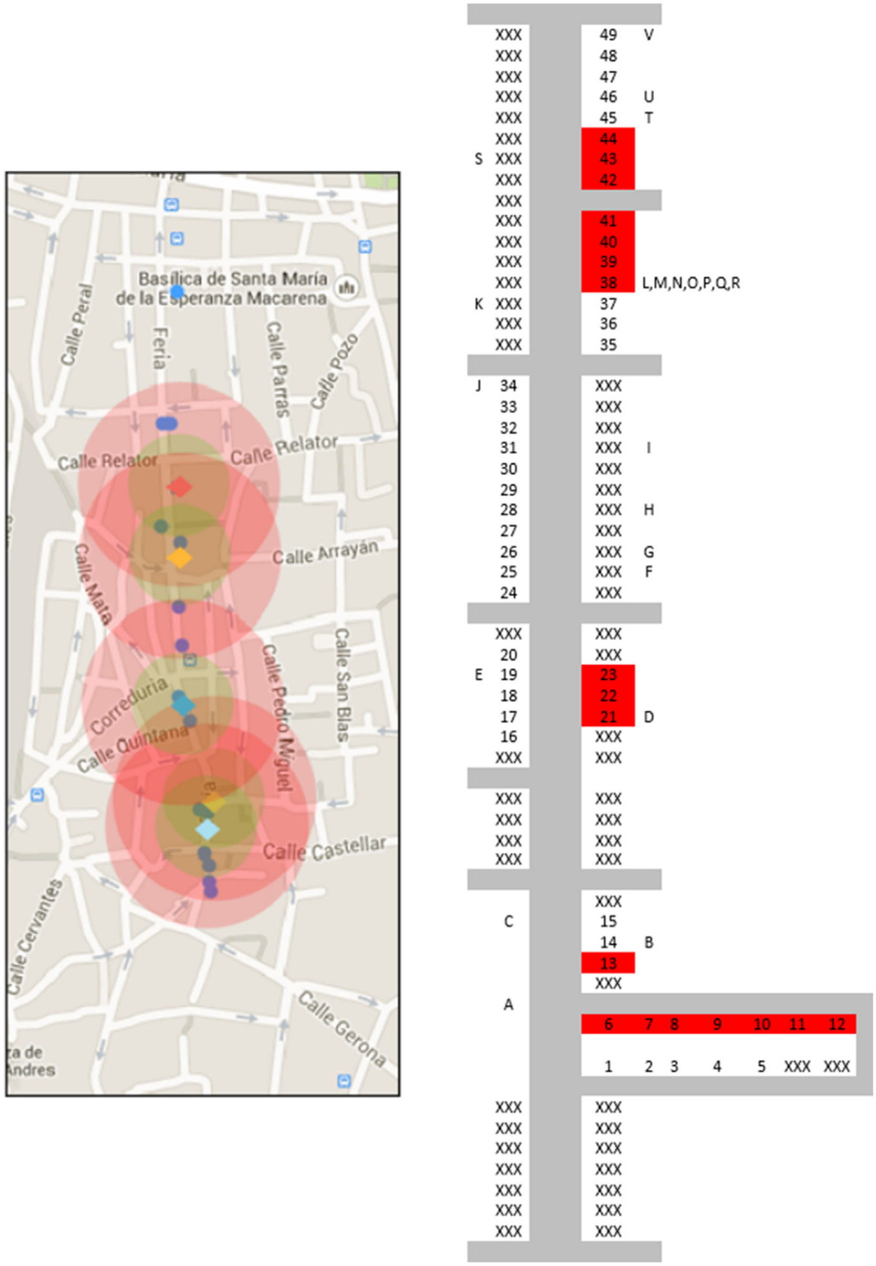

Fig. 2. Location of retail premises and coverage of loading zones in Feria street (left); schematic representation of the street (right), with the existing loading zones marked in red, the commercial establishments marked with letters, parking spaces marked with numbers and segments without parking spaces marked with "XXX". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

minutes per day) corresponding to each establishment j is equal to:

$$D'_j = f_j \cdot e_j \tag{1}$$

However, the actual capacity demand is likely to be higher than the theoretical one, since the arrivals of delivery vehicles are not synchronized, and their desired residence times in loading zones are likely to overlap. The easiest way to respond to this problem is to follow the recommendation of CERTU (2009), establishing a desired level of service LS as a ratio between the actual loading zone capacity demand D_j and the theoretical loading zone capacity demand D'_j, as follows:

$$D_j = LS \cdot D'_j \tag{2}$$

This level of service is a parameter to be decided upon by the local authorities for each individual street (or street segment, or group of streets) where loading zones are to be provided. In the case of the CERTU procedure, the number of deliveries served on an average week in a given road segment is divided by 90 to determine the theoretical number of loading bays needed (Gardrat and Serouge 2016). Then, the actual number of loading bays to provide would be obtained by multiplying that theoretical number by the level of service LS.

In our case, we consider the working day divided into T one-hour periods ($t = 1 \ldots T$), whereupon, for each period t, $f_{jt} = f_j \cdot \delta_{jt}$, with δ_{jt} equal to 1 if establishment j may receive deliveries during period t and 0 otherwise. If a given establishment j receives f_j deliveries per day but may receive them distributed during e.g. the morning hours, then all the δ_{jt} values corresponding to those morning periods will be equal to 1, representing that establishment j will require loading zone capacity during all those periods. This in fact multiplies the loading zone demand for each establishment, given that the f_{jt} values would result as if establishment j received all its f_j deliveries during each morning period, but

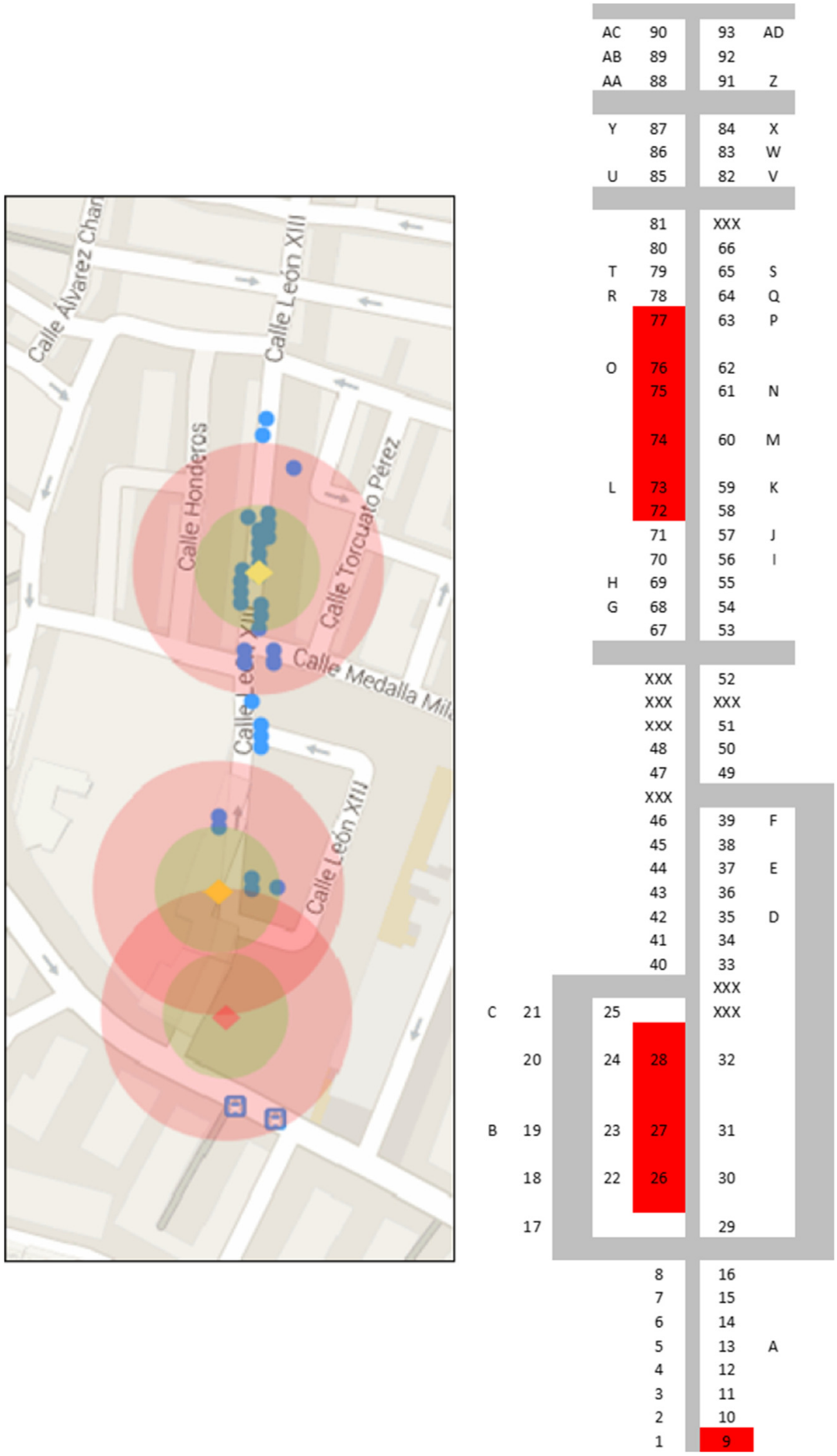

Fig. 3. Location of retail premises and coverage of loading zones in León XIII street (left); schematic representation of the street (right), with the existing loading zones marked in red, the commercial establishments marked with letters, parking spaces marked with numbers and segments without parking spaces marked with "XXX". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

this accounts for the fact that establishments are often unable to be too specific about their exact delivery periods.

Following the above, we contemplate three possible approaches to estimate the total loading zone demand D:

a) Average demand: this option considers that the loading zone demand in the street corresponds to the average loading zone demand for all the periods. This may be considered as a lower bound, as it assumes that loading zone demand is flexible enough to be accommodated across periods.

b) Peak demand: this second option takes the period with highest loading zone demand, and assumes that the loading zone capacity should take that peak period as a reference.

c) Coincident demand: this last approach is similar to the previous one, but rounding all the delivery frequencies to the next integer, so that the loading zone demand is calculated as if all the possible deliveries

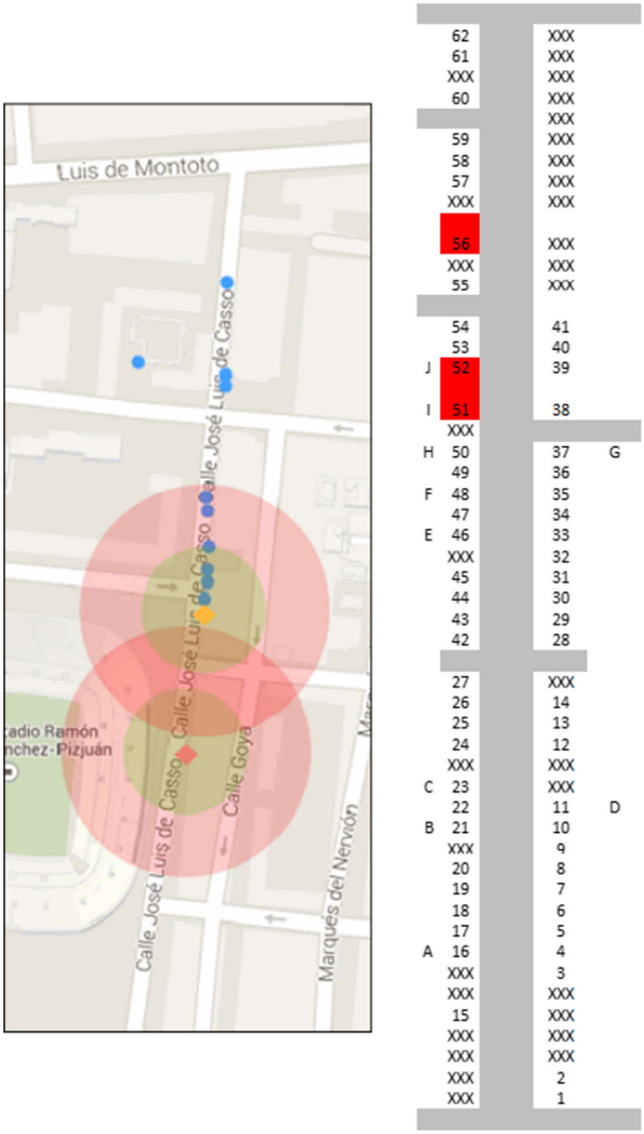

Fig. 4. Location of retail premises and coverage of loading zones in José Luis de Casso street (left); schematic representation of the street (right), with the existing loading zones marked in red, the commercial establishments marked with letters, parking spaces marked with numbers and segments without parking spaces marked with "XXX". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

that may be received by each establishment on a given day were received on the same period.

Table 1 shows the mathematical calculations corresponding to each approach. Thereafter, the minimum number N of loading zones to provide can be estimated as $N = D/C$, where C is the capacity of each loading zone, measured as the time during which the loading zone is operative. It is worth noting here that N should be taken as a lower bound, and corresponds to the minimum theoretical number of loading zones required to accommodate parking demand on a given street. Providing a number of loading zones larger than N would result in a smoother operation of deliveries, in a situation equivalent to the provision of excess capacity in a scheduling problem. In any case, the quantification problem is independent from the location-allocation part, and the second one can be carried out for any chosen number of loading zones, whether this number is higher, equal to, or lower than N. Additionally, the determination of the minimum number or required loading zones can represent a relevant input for political decision-making processes with respect to e.g. pedestrianization initiatives, redesign of urban areas, etc.

2.2. Location-allocation problem

Once the number N of loading zones to provide on a given street (or street segment, or group of streets) is determined, the selection of locations can be carried out by solving a specific location-allocation problem (Scott 1970). The variables of this problem are the following:

$y_i = 1$ if parking space i is selected as a loading zone, 0 otherwise

x_{ij} = amount of loading zone demand corresponding to establishment j which is assigned to loading zone i

Apart from the parameters described in the previous section, the modelling of the problem requires to know the value of d_{ij} for each potential loading zone i and each establishment j, which is equal to the distance between i and j. The location-allocation problem can then be modelled as follows:

$$Min \quad \sum_i \sum_j d_{ij} \cdot x_{ij} \tag{3}$$

$$s.to : \sum_i y_i = N \tag{4}$$

$$\sum_i x_{ij} = D_j \quad \forall j \tag{5}$$

$$\sum_j x_{ij} \le C_i \cdot y_i \quad \forall i \tag{6}$$

$$y_i \in \{0, 1\}, x_{ij} \ge 0 \tag{7}$$

In this mathematical model, the objective function [3] minimizes the sum of products of distances and demands (*MinDist* approach), in order to allocate establishments to the closest loading zones. Constraint [4] forces the number of loading zones to activate, and constraints [5] ensure that all the loading zone demand corresponding to each establishment is allocated. Constraint [6] forces the amount of demand that can be allocated to each potential loading zone, including the fact that a loading zone can only accommodate demand if it is activated. Finally, constraints [7] establish the binary character of variables y_i and the non-negative character of x_{ij}.

However, given the public service character of loading zones, a further refinement of the procedure may be achieved by a *MiniMax* approach (Ogryczak 1997), where the objective is not to minimize the sum of all products of distances and demands, but to minimize the maximum product of distance and demand for each establishment. This alternative formulation is shown below:

$$Min \quad Z \tag{8}$$

$$s.to : \sum_i d_{ij} \cdot x_{ij} \le Z \quad \forall j \tag{9}$$

Eqs. (4) to (7).

After solving the model, and depending on the results obtained, it may be desirable to include small modifications in the distribution of loading zones. For instance, if the model suggests to place two loading zones separated by a single parking space it may be desirable to put them together when actually implementing the system on the street.

3. Case study

Seeking to validate this methodology, we tested it in four streets with high commercial and residential density in the city of Seville, in the South of Spain. Like in many other Spanish and European cities,

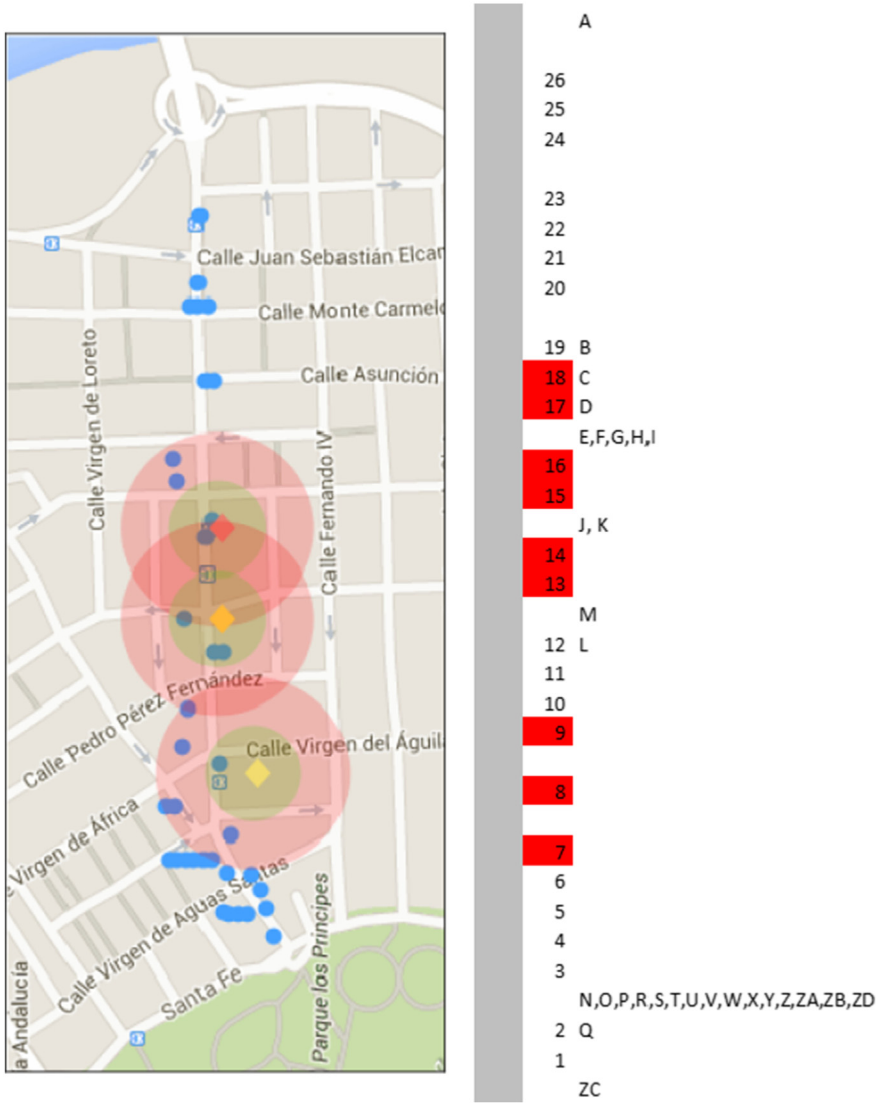

Fig. 5. Location of retail premises and coverage of loading zones in Virgen de Luján street (left); schematic representation of the street (right), with the existing loading zones marked in red, the commercial establishments marked with letters, parking spaces marked with numbers and segments without parking spaces marked with "XXX". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the management of loading zone infrastructure is an unresolved issue, with problems related to vehicle rotation, time windows and regulation enforcement (Muñuzuri et al. 2012), and lacking a predefined procedure for the design and provision of loading zone systems.

With respect to the four streets chosen, Feria Street is the main exit gate in the historical city center; León XIII is the main arterial road in a densely populated district close to the historical area; José Luis de Casso links two avenues with high traffic flows in the newer part of the city; and Virgen de Luján is an urban avenue crossing a high-income neighborhood. Together they add up to 92 retail premises of many different types, and they all present a congested combination of passenger cars, delivery vehicles and public transport.

3.1. Street configuration

Fig. 1 shows the locations of these four streets in the city map, and Figs. 2 to 5 show the details of each one. They have 18, 10, 3 and 9 loading zones respectively, and the area coverage provided by these loading zones is also depicted in Figs. 2 to 5, showing the location of the different retail establishments and the 25 m and 50 m influence radius areas for each loading zone. Table 2 shows the area coverage provided by loading zones in the analyzed streets, as well as the average loading zone occupation measured during a week's field observations carried out in March 2015. We believe that these indicators highlight the potential improvements in the management of loading zones.

Table 2
Average loading zone data in the analyzed streets.

Street	Establishments with loading zone within 25 m	Establishments with loading zone within 50 m	Average loading zone occupation
Feria	44%	72%	70%
León XIII	28%	62%	38%
José Luis de Casso	30%	40%	53%
Virgen de Luján	11%	17%	27%

Table 3
Delivery data for Feria Street.

Shop type	Code in Fig. 2	Daily frequency (deliveries per day)	Delivery time (min)	Schedule	Daily demand (min/day)	Time period													
						7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21
Druggist	S	1	15	All day	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Pharmacy	A, V	3	5	9–11 & 16–17	15			15	15						15				
Paintings and frames	U	1	7.5	9–16 & 17 to 18	7.5		7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5		7.5			
Books	T	0.5	12.5	11–14	6.25					6.25	6.25	6.25							
Seeds	E	1	5	12–13	5						5								
Bakery	J, K	1	7.5	8–12	7.5		7.5	7.5	7.5	7.5									
Fruits and vegetables	B, M	1	45	7–11	45	45	45	45	45										
Butcher	N, O	1	12.5	10–16	12.5				12.5	12.5	12.5	12.5	12.5	12.5					
Deli	P	1	5	10–11	5				5										
Minimarket	H	4	12.5	7–8	50	50													
Fish	Q, R	1	30	7–9	30	30	30												
Takeaway	I	1	12.5	8–13	12.5		12.5	12.5	12.5	12.5	12.5								
Parapharmacy	L	0.2	5	18–19	1												1		
Optometrist	G	4	5	10–13	20				20	20	20								
Furniture	C	0.1	7.5	9–14	0.75			0.75	0.75	0.75	0.75	0.75							
Pet shop	F	0.2	5	10–12	1				1	1									
	Demand per period (min)					215	200	170.75	221.75	103	92	54.5	47.5	47.5	45	22.5	16	15	15

3.2. Retailer surveys

In order to gather the required information for the application of the methodology, we carried out a detailed field survey, interviewing all the shops located in the four analyzed streets. The surveys covered all the aspects related to the freight deliveries received by the shop, and contained the following questions:

- How often do you receive deliveries?
- What days of the week do you typically receive deliveries?
- What time do you typically receive those deliveries?
- The goods are delivered by the provider, by yourself, or by a third-party carrier?
- What types of vehicles are used for the deliveries?
- Where do the vehicles typically park?
- How is the final delivery made: by hand, on a handcart or using a pallet truck?
- How long does the delivery process take?

The following Tables 3 to 6 show the delivery data obtained from the retailer surveys at the four analyzed streets, including the daily delivery

Table 4
Delivery data for León XIII Street.

Shop type	Code in Fig. 3	Daily frequency (deliveries per day)	Delivery time (min)	Schedule	Daily demand (min/day)	Time period													
						7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21
Stationery	C	0.1	10	All day	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Toys	Q	1	10	All day	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Bakery	H, S	2.5	7.5	8–12	18.75		18.75	18.75	18.75	18.75									
Butcher	L	1	12.5	10–16	12.5				12.5	12.5	12.5	12.5	12.5	12.5					
Fish	N	1	30	7–9	30	30	30												
Deli	V	2	15	7–12	30	30	30	30	30	30									
Fruits and vegetables	E, AA, AC	1	45	7–11	45	45	45	45	45										
Clothes	T, X, Y	0.2	7.5	All day	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Shoe repairs	F	0.3	7.5	12–13 & 17–18	2.25						2.25					2.25			
Babies	W	1	7.5	All day	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Hairdresser	A, G, J	0.3	7.5	All day	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Bar/café	B, I, R, Z	3	7.5	8–15	22.5		22.5	22.5	22.5	22.5	22.5	22.5	22.5						
Parapharmacy	AB	0.1	5	18–19	0.5												0.5		
Dry cleaner	K	0.1	7.5	All day	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Tobacconist	M	0.1	5	11–14	0.5					0.5	0.5	0.5							
Pharmacy	AD	5	5	9–11 & 18–19	25			25	25								25		
Furniture	D	1	7.5	10–11	7.5				7.5										
Lingerie	P	0.5	12.5	10–14	6.25				6.25	6.25	6.25	6.25							
Press	O	2	5	7–11	10	10	10	10	10										
Perfumes	U	1	27.5	9–10	27.5			27.5											
	Demand per period (min)					245	372.5	395	393.75	261.75	196.5	131.75	125	35	22.5	24.75	48	22.5	22.5

Table 5
Delivery data for José Luis de Casso Street.

Shop type	Code in Fig. 4	Daily frequency (deliveries per day)	Delivery time (min)	Schedule	Daily demand (min/day)	Time period													
						7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21
Restaurant	C	1	17.5	11–14	17.5					17.5	17.5	17.5							
Bar/café	A, I	1	7.5	8–15	7.5		7.5	7.5	7.5	7.5	7.5	7.5	7.5						
Press	G	2	5	7–11	10	10	10	10	10										
Books	H	0.3	12.5	All day	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Clothes	J	0.5	7.5	All day	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Computers	E	0.3	7.5	10–11	2.25				2.25										
Butcher	F	5	12.5	7–13	62.5	62.5	62.5	62.5	62.5	62.5	62.5								
Minimarket	B	2.5	7.5	8–12	18.75		18.75	18.75	18.75	18.75									
Fish	D	1	30	7–9	30	30	30												
	Demand per period (min)					110	143.75	113.75	116	121.25	102.5	40	22.5	7.5	7.5	7.5	7.5	7.5	7.5

frequency (f_i), delivery time (e_i) and daily loading zone demand (D_i). The "time period" columns contain the demand values for each one-hour period ($f_{it} \cdots e_i$). There is also a column in each table showing the letter codes which correspond to each type of establishment in Figs. 2 to 5; it should therefore be noted that establishment types with only one letter code appear only once in the corresponding street, whereas those with two, three or four codes appear two, three or four times respectively.

These surveys confirmed that, except for fresh food retailers, supermarkets and other activities, most commercial premises open their doors at 10.00, stop for lunch between 14.00 and 17.00 and finish their day around 20.30. This Spanish pattern is notably different from the Italian example of Bologna (Dezi et al. 2010), but similar to the French pattern (Gardrat and Serouge 2016), with displaced peaks due to the different working hours.

It is interesting to note that the delivery frequency data collected in our surveys is very different from the information reported by Gardrat and Serouge (2016) for the French cities of Bordeaux and Lyon and by Alho and De Abreu e Silva (2014) for the Portuguese city of Lisbon, which two datasets also differ notably. This is an unexpected outcome that confirms the risks involved in using directly frequency values taken from other geographical locations instead of carrying out specific surveys in each case.

4. Framework analysis

Using the data presented in the previous section, Table 7 shows the results of the application of the three quantification procedures described in Section 2.1, and a comparison with these results and the ones provided by the CERTU (2009) methodology, determined by dividing the total number of weekly deliveries by 90.

In order to validate the procedure, instead of directly selecting one of the three quantification approaches we solved the location-allocation models for different scenarios involving different numbers of loading zones in the four streets. Table 8 shows the locations selected for loading zones in the four streets, both for the *MinDist* and *MiniMax* approaches, in each one of these scenarios.

Fig. 6 represents the results for one of those scenarios and compare them with the current loading zone distribution in Feria Street. The objective is to show how the results obtained affect the distance to cover between the assigned loading zones and the final destinations. The figures show an improvement in both cases (*MinDist* and *MiniMax* approaches) with respect to the current scenario, where many establishments are adequately serviced by the existing loading zones but several others are too far away from them to benefit from the use of this public infrastructure. As a consequence, the area coverage provided by the existing loading zones can be considered incomplete.

Fig. 6 also shows that the *MinDist* approach results in more efficient outcomes than the *MiniMax* case. Nevertheless, the difference between both approaches decreases as the number of loading zones in the street grows larger. This tendency, depicted in Fig. 7, is similar for all the analyzed scenarios in the four streets.

5. Simulation

After obtaining loading zone locations for all the scenarios contemplated in the previous section, we completed the validation of the results using microscopic simulation. This technique has been used in several recent research works (Motraghi and Marinov 2012; Walker and Manson 2014; Aditjandra et al. 2016) to represent the complexity of urban freight systems and the decision-making processes involved.

In our case, we discarded the inclusion of cars and public transport in the simulations, since their interaction with delivery vehicles is limited to congestion effects and subsequent speed values, but has no theoretical influence over loading zone availability, as long as illegal parking is avoided. Our objective was to simulate the random arrivals of delivery vehicles and their parking processes, which result in the occupation of loading zone spaces. The interaction between delivery vehicles and general traffic has been addressed in works like Muñuzuri et al. (2013) or Alho et al. (2014), where the idea was to analyze the delays and additional driving times induced by congestion on delivery vehicles. In our case, however, it is only the number, location and availability of loading zones what needs to be analyzed, and not a full representation of urban freight mobility, upon which the additional modelling complexity and data required to incorporate cars and buses into the simulations can be avoided.

We built simulation scenarios for each one of the four streets using the Arena® simulation package, following the structure depicted in Fig. 8. Each scenario is composed by the road, represented by a conveyor with a fixed speed, and the different loading zones, modelled as resources and located at the spots indicated by the location-allocation model in each case. Delivery vehicles enter the simulation following a uniform distribution dependent on the delivery pattern of the retailer they have to service, and have a specific loading zone assigned according to their final destination. However, if that loading zone is occupied they are allowed to stop at another one as long as a 50 m distance threshold is not exceeded. If a certain delivery vehicle cannot find an available loading zone, it continues moving down the street until it exits the simulation, and returns after a random period modelled by a normal distribution with mean equal to 15 min and a large standard deviation (± 10 min). The parking of delivery vehicles in regular parking spaces, outside loading zones, is not contemplated since this possibility never took place in the observed scenarios, with all the parking spaces saturated by cars. With respect to the stopping time of vehicles in loading zones, it is modelled in the simulation as $e_i + v_f \cdots d_{ij}$, where v_f is the on-foot speed for final deliveries, established equal to 5 km/h.

We run the simulation process (see Fig. 9) for all the different scenarios built by providing different numbers of loading zones on each

Table 6
Delivery data for Virgen de Luján Street.

Shop type	Code in Fig. 5	Daily frequency (deliveries per day)	Delivery time (min)	Schedule	Daily demand (min/day)	Time period													
						7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21
Fish	M	1	30	7–9	30	30	30												
Butcher	V	1	12.5	7–11	12.5	12.5	12.5	12.5	12.5										
Fruit and vegetables	W	1	45	7–11	45	45	45	45	45										
Deli	B, N	0.5	5	10–11	2.5				2.5										
Liquors	T	0.2	12.5	11–15	2.5					2.5	2.5	2.5	2.5						
Health center	H	5	5	9–14	25			25	25	25	25	25							
Videogames	L	0.3	5	10–14	1.5				1.5	1.5	1.5	1.5							
Computers	U	0.3	7.5	10–11	2.25				2.25										
Phones	X, ZC	1	5	9–15	5			5	5	5	5	5	5						
Bar/café	A, G, S	1	7.5	8–15	7.5		7.5	7.5	7.5	7.5	7.5	7.5	7.5						
Restaurant	I	1	17.5	11–14	17.5					17.5	17.5	17.5							
Orthopedist		1	5	9–11	5			5	5										
Boutique	J	0.3	7.5	All day	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Home appliances	Y	0.3	7.5	All day	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Clothes	D	0.5	7.5	All day	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75		
Complements	K	0.2	5	10–15	1				1	1	1	1	1						
Lottery	O	0.2	5	10–11	1				1										
Hardware	C	0.2	10	9–13	2			2	2	2	2								
Optometrist	P, ZA	1	5	10–15	5				5	5	5	5	5						
Bike repairs	E	0.5	5	15–21	2.5									2.5	2.5	2.5	2.5	2.5	2.5
Car repairs	Z	1	5	11–16	5					5	5	5	5	5					
Music instruments	Q	0.8	7.5	All day	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Printers	ZB	0.5	7.5	10–15	3.75				3.75	3.75	3.75	3.75	3.75						
Florist	ZD	0.3	12.5	9–14	3.75			3.75	3.75	3.75	3.75	3.75							
Pharmacy	F	2	5	9–11 & 18–19	10			10	10								10		
Veterinary	R	1	5	10–15 & 16–21	5				5	5	5	5	5		5	5	5	5	5
	Demand per period (min)					101.75	131.75	157.5	187	136.25	136.25	134.25	86.5	26.75	21.75	21.75	31.75	18	18

Table 7
Comparison between the minimum required number of loading zones to accommodate demand in the four analyzed streets and the existing number of loading zones in them.

Street	Theoretical number of loading zones needed according to our calculations			Weekly deliveries	Theoretical number of loading zones needed according to CERTU (2009)	Existing loading zones
	a)	b)	c)			
Feria	2	4	6	276	3	18
León XIII	3	7	10	235	3	10
José Luis de Casso	1	3	3	101	1	3
Virgen de Luján	2	3	6	185	2	9

one of the four streets. Each scenario was run 10 times in order to obtain average values, and contemplated only the morning hours (7.00 to 15.00), which concentrate most part of the loading zone demand of the four streets (see Tables 3 to 6). The results obtained are shown in Tables 9 to 12, including the percentage of returns due to the unavailability of loading zone spaces (this number might be larger than 100% if vehicles typically have to return more than once), the loading zone use percentage (average, minimum and maximum), and the average distance between the used loading zone and the destination retailer.

The most relevant result of the simulations is the percentage of returns, as it indicates the amount of delivery vehicles that are forced to alter their route due to the unavailability of parking space. If the lack of loading zone space is one of the main difficulties identified by carriers (Vidal Vieira et al. 2015) and the objective of a loading zone optimization process is to provide maximum service with the minimum number of loading zones, the percentage of returns constitutes the main indicator of the level of service, and should decrease as the number of loading zones grows.

Regarding this percentage of returns, the simulations show similar results for the *MinDist* and *MaxiMin* approaches. Furthermore, the results clearly show the existence of thresholds in the number of loading zones, which improve the level of service provided by the current scenario. In the case of Feria Street this threshold can be established in 12 loading zones, 8 in León XIII, 3 in José Luis de Casso and 8 in Virgen de Luján. This means that an increase of around 10–15% in the number of loading zones estimated following the assumption of coincident

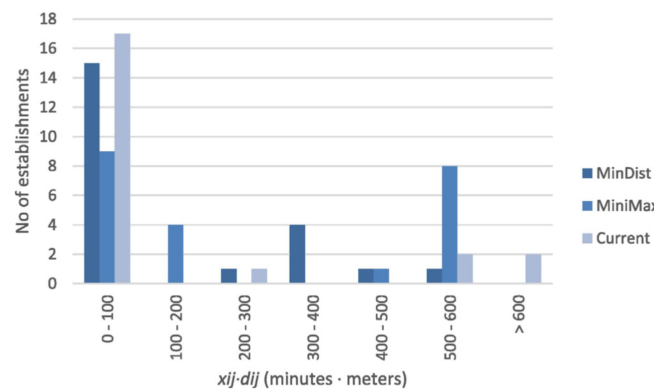

Fig. 6. Comparison between the *MinDist* and *MiniMax* approaches in Feria Street for the scenario with 4 loading zones and the current scenario with 18 loading zones.

demand (approach *c*) results in levels of service corresponding to return percentages below 5%.

It is interesting to note that the loading zone occupation data returned by the simulations is 50% lower than the observations compiled in Table 2, which leads to the possibility of retailers underestimating the duration of stops when answering our survey. Another possibility is that deliveries do take the reduced amount of time revealed by retailers, but drivers leave the vehicle parked for longer periods of time while they take a rest, make a delivery at another shop, etc. Direct observations appear then as a more adequate procedure to

Table 8
Location-allocation results obtained for Feria Street.

Street	Nº of loading zones	*MinDist* results	*MiniMax* results
Feria	2	14, 38	12, 32
	4	14, 28, 38, 46	14, 28, 38, 48
	6	6, 14, 21, 28, 38, 46	7, 14, 17, 28, 38, 46
	8	6, 14, 23, 26, 28, 38, 43, 49	1, 14, 18, 26, 28, 31, 38, 46
	12	6, 14, 23, 26, 28, 31, 34, 37, 38, 43, 46, 49	6, 14, 19, 26, 28, 31, 34, 37, 38, 43, 46, 49
León XIII	3	41, 77, 91	42, 64, 87
	6	23, 41, 59, 66, 78, 90	23, 43, 60, 63, 80, 90
	10	9, 23, 30, 42, 59, 66, 72, 77, 82, 91	12, 22, 41, 60, 65, 72, 79, 89, 90, 92
	14	9, 23, 42, 57, 60, 66, 67, 72, 78, 81, 84, 88, 90, 93	12, 23, 42, 58, 60, 66, 68, 73, 78, 82, 84, 89, 90, 93
	16	9, 30, 38, 41, 58, 60, 66, 68, 72, 76, 78, 81, 83, 88, 91, 93	10, 26, 30, 42, 57, 60, 66, 67, 71, 75, 78, 82, 84, 88, 91, 92
José Luis de Casso	1	19	24
	2	19, 45	19, 45
	3	5, 19, 45	5, 19, 43
	5	5, 17, 18, 20, 45	5, 17, 18, 20, 43
	6	5, 17, 18, 20, 41, 45	5, 17, 18, 20, 42, 45
Virgen de Luján	2	3, 17	4, 17
	4	3, 16, 17, 26	1, 3, 16, 17
	6	1, 3, 12, 16, 17, 26	1, 3, 12, 16, 17, 26
	8	1, 3, 7, 12, 15, 16, 17, 26	1, 2, 3, 7, 12, 16, 17, 26
	10	1, 3, 7, 12, 15, 16, 17, 18, 19, 26	1, 2, 3, 7, 12, 15, 16, 17, 19, 26

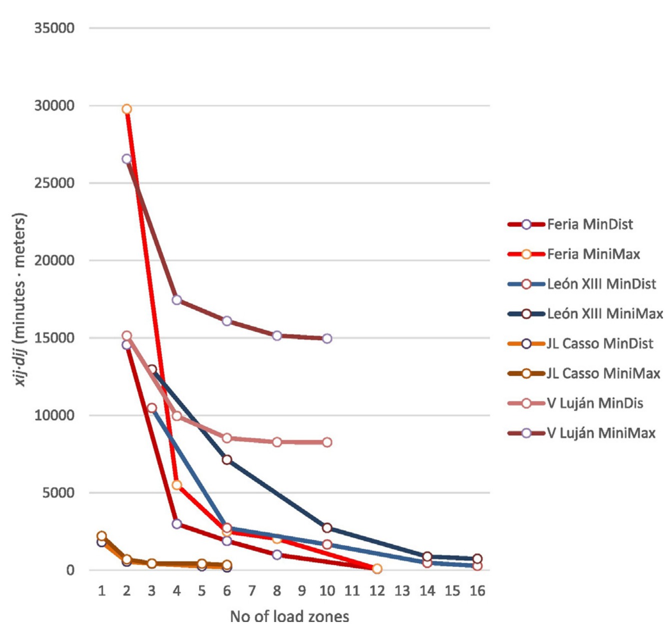

Fig. 7. Comparison between the *MinDist* and *MiniMax* approaches for different numbers of loading zones in the analyzed streets.

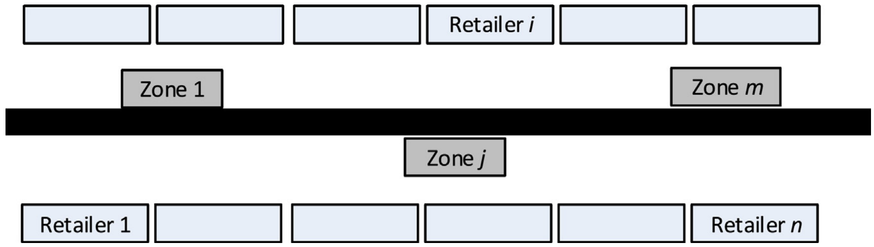

Fig. 8. Example of simulation scenario.

represent reality than surveys, but the effects of the lack of rotation enforcement should be discounted in order to obtain accurate estimations.

According to the simulations, and following the CERTU (2009) terminology, the use of an average demand quantification approach calls for the introduction of a level of service parameter *LS* equal to 4, peak demand requires *LS* equal to 2, and *LS* is equal to 1 for coincident demand (see Table 13). In any case, the comparison with the existing number of loading zones shows that the proposed reduction is not too significant except for the case of Feria. Finally, the most relevant improvement introduced by the proposed methodology is related to the average distance between loading zones and retailers, which in the threshold scenarios is reduced by almost 50% with respect to the current situation for a similar number of loading zones. This is the other main indicator to measure the level of service provided by the loading zone system, focusing specifically on the location of the spaces, and in this case the superiority of the *MinDist* approach over the *MaxiMin* is clear, as shown previously in Figs. 6 and 7.

6. Conclusions

Local authorities are often forced to rely on intuition when implementing urban freight policies, due to the complexity of the processes and generalized lack of data and validated procedures. Nevertheless, in the case of loading zones, the ubiquity of this dedicated infrastructure in cities around the world calls for the development of a procedure to determine the number of loading zones required on a given street or area and their ideal locations. This is particularly so since in many cases loading zones can be found in central areas of the city, where space is scarce and parking spaces for cars are often subject to metered payment policies. This means that, while underestimating the number of loading zones required has an immediate impact on carrier costs and level of service, overestimating it also reduces income for the municipality and leads to the inefficient use of space.

In the procedure we have presented here, the first step consists of choosing an approach to estimate loading zone demand, combining it

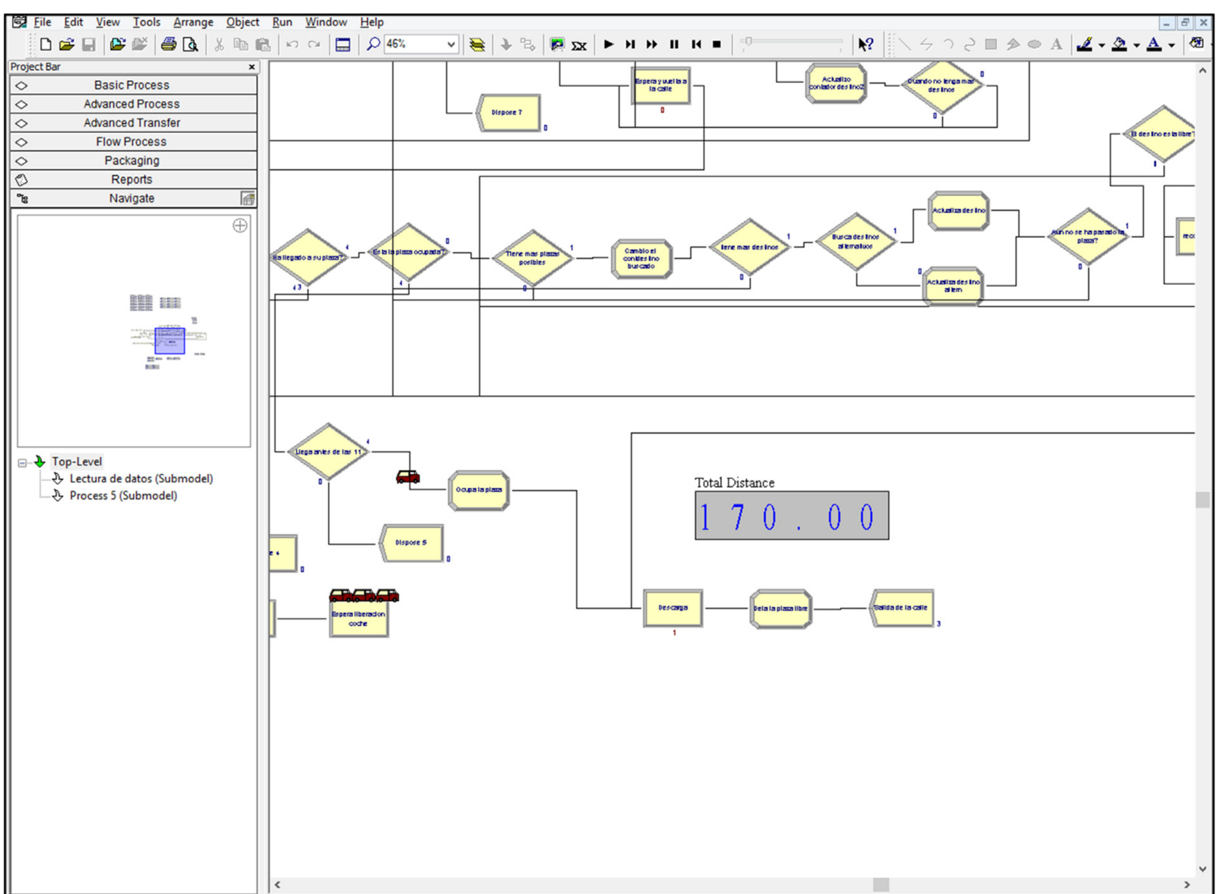

Fig. 9. Screenshot of the Arena simulation process developed.

Table 9
Simulation results for Feria Street. The last line corresponds to the simulation of the current scenario.

	MinDist Approach					*MiniMax* Approach				
Nº of loading zones	% Returns	% Loading zone use			Average Distance (m)	% Returns	% Loading zone use			Average Distance (m)
		Average	Min	Max			Average	Min	Max	
2	245%	47%	22%	73%	35	231%	48%	20%	77%	50
4	33%	42%	21%	54%	47	34%	43%	23%	58%	49
6	14%	30%	8%	55%	43	17%	29%	9%	58%	44
8	4%	22%	7%	50%	25	7%	23%	6%	50%	26
12	0%	15%	5%	40%	9	0%	15%	5%	38%	10
18	**1%**	**10%**	**0%**	**52%**	**17**	**1%**	**10%**	**0%**	**52%**	**17**

Table 10
Simulation results for León XIII Street. The last line corresponds to the simulation of the current scenario.

	MinDist Approach					*MiniMax* Approach				
Nº of loading zones	% Returns	% Loading zone use			Average Distance (m)	% Returns	% Loading zone use			Average Distance (m)
		Average	Min	Max			Average	Min	Max	
3	155%	53%	46%	59%	55	157%	54%	50%		63
6	36%	36%	16%	54%	37	29%	36%	24%	49%	48
10	7%	28%	71%	36%	20	5%	28%	71%	33%	24
14	2%	16%	4%	26%	8	1%	16%	5%	26%	6
16	1%	14%	4%	26%	5	2%	14%	3%	27%	5
10	**31%**	**22%**	**0%**	**53%**	**55**	**31%**	**22%**	**0%**	**53%**	**55**

with the appropriate value of the level of service parameter (*LS*) as argued in the previous section. This results in an estimation of the number of loading zones required, and then the *MinDist* location-allocation problem provides the best locations for them. Our simulations have proved that significant improvements on delivery distance can be achieved with a smaller number of loading zones as long as they are conveniently placed.

It is true that the application of this methodology (as in the CERTU case) requires the completion of retailer surveys in order to obtain data on delivery frequencies and durations. Despite the fact that similar commercial establishments are likely to present similar delivery patterns, this hypothesis should be handled with care, particularly for very different geographical locations, since the heterogeneous consideration of information in different geographical locations is typical of urban freight data, as shown by several comparative studies completed at European level (Ambrosini and Routhier 2004).

In any case, the decision-making process concerning the provision of loading zones on commercial streets is not limited to the quantitative methodology described here. Many other aspects need to be solved as well, political decisions addressing established practices that often incorporate additional inefficiencies to urban freight systems (Muñuzuri et al. 2012):

- What can be done with own-account carriers, who often leave their vehicles parked in loading zones during most part of the day ignoring rotation regulations?
- What level of enforcement is desirable?
- The procedure presented here is mainly of application in central areas of cities, where streets are single-lane and narrow, and the only option for freight deliveries is the use of loading zones. However, the question remains about the strategy to follow in the case of streets with more than one lane, where double-parking in front of

Table 11
Simulation results for José Luis de Casso Street. The last line corresponds to the simulation of the current scenario.

	MinDist Approach					*MiniMax* Approach				
N° of loading zones	% Returns	% Loading zone use			Average Distance (m)	% Returns	% Loading zone use			Average Distance (m)
		Average	Min	Max			Average	Min	Max	
1	220%	53%	53%	53%	33	199%	54%	54%	54%	31
2	54%	36%	33%	39%	16	39%	36%	32%	40%	18
3	12%	25%	14%	36%	20	7%	25%	15%	33%	19
5	1%	15%	6%	33%	16	1%	15%	4%	34%	16
6	1%	13%	3%	33%	8	3%	13%	4%	30%	9
3	**40%**	**25%**	**0%**	**39%**	**36**	**40%**	**25%**	**0%**	**39%**	**36**

Table 12
Simulation results for Virgen de Luján Street. The last line corresponds to the simulation of the current scenario.

	MinDist Approach					*MiniMax* Approach				
Nº of loading zones	% Returns	% Loading zone use			Average Distance (m)	% Returns	% Loading zone use			Average Distance (m)
		Average	Min	Max			Average	Min	Max	
2	119%	39%	29%	49%	77	119%	40%	30%	49%	75
4	67%	25%	12%	47%	59	69%	25%	13%	50%	44
6	28%	19%	11%	45%	39	28%	19%	11%	45%	39
8	4%	16%	9%	39%	40	4%	16%	9%	39%	40
10	3%	11%	1%	38%	34	3%	11%	0%	39%	37
9	**5%**	**15%**	**5%**	**43%**	**71**	**5%**	**15%**	**5%**	**43%**	**71**

Table 13
Suggested value of *LS* depending on the quantification approach selected to approximate the actual number of loading zones required according to the simulations.

	Street	Quantification approach		
		a) Average demand	b) Peak demand	c) Coincident demand
Theoretical number of loading zones needed	Feria	2	4	6
	León XIII	3	7	10
	José Luis de Casso	1	3	3
	Virgen de Luján	2	3	6
Suggested value of *LS*		**4**	**2**	**1**
Actual number of loading zones recommended	Feria	8	8	6
	León XIII	12	14	10
	José Luis de Casso	4	6	3
	Virgen de Luján	8	6	6

the receiver is a possibility.

- When is it necessary to provide loading zones on a given street?

Finally, we have only considered a constant number of loading zones available throughout the different periods, assuming that loading zone time windows operate in such a way that either all the loading zones are available for loading/unloading, or none of them is. The possibility of relaxing this assumption could be contemplated as a possible future research objective.

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