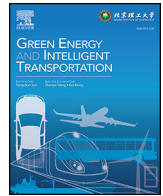




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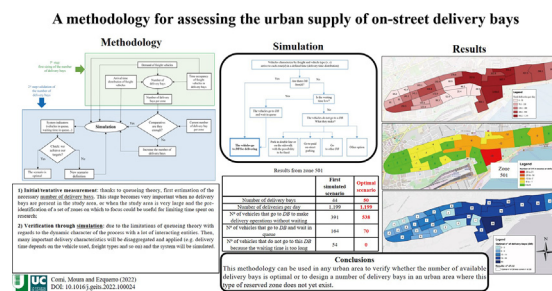
A methodology for assessing the urban supply of on-street delivery bays

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HIGHLIGHTS

- The paper proposes a methodology to design urban delivery bay system.
- Freight operation scenarios are assessed through a simulation-based approach.
- The results were validated in Santander.

GRAPHICAL ABSTRACT



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ABSTRACT

The loading and unloading operations carried out by transport and logistics operators have a strong impact on city mobility if they are not performed correctly. If loading/unloading bays, i.e., delivery bays (DB), are not available for freight vehicle operations, operators may opt to double park or park on the sidewalk where there is no strong enforcement of these laws, with significant impact on congestion. This paper proposes a methodology for verifying and designing the number of delivery bays needed for freight vehicles for not interfere with cars or pedestrians. The methodology consists of two stages: in the first stage, an initial estimation is made using queuing theory. Subsequently, in the second stage, using such tentative scenario, in order to take into account the system stochasticity involving different entities, a discrete event simulation is performed to more realistically verify and upgrade (if necessary) the number of delivery bays to obtain the expected outcomes. The methodology was applied in the inner area of Santander (Spain). The study area was subdivided into 29 zones where the methodology was applied individually. The results indicated that none of these zones currently have an optimal number of delivery bays to satisfy demand. In some zones, there is an excess of delivery bays, although in most of them, there is a deficit which can cause significant impacts on traffic. The method proposed can be an effective tool to be used by city planners for improving freight operations in urban areas limiting the negative impacts produced in terms of internal and external costs.

1. Introduction

Freight transport has a large impact on cities because it contributes to congestion and pollution. Therefore, it is important to regulate freight

transport as well as to optimize the number of vehicles, the kilometres travelled as well as the loading and unloading operations. Such operations, if not performed properly, can significantly impact mobility in cities. In fact, local conditions could push freight vehicles to stop for

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loading and unloading outside designated spaces, as well as to stop at junctions or along a lane, in both cases causing a road capacity reduction, with a subsequent deterioration of network performances, or road accidents (Russo and Comi [45]; Comi et al. [20]).

Various measures have been implemented around the world to alleviate the problems generated by the freight distribution (Ezquerro et al. [31]; Russo and Comi [44]; Comi [11]; Gómez-Marín et al. [32]; Comi and Savchenko [14]; Battaglia et al. [6]). Some of these strategies aim to regulate freight vehicle access through restrictions on vehicle surface, gross vehicle weight or pollutant emissions, or through time restrictions that establish time windows during which they are allowed access to the city (Anderson et al. [4]; Comi et al. [18]; Russo and Comi [46]). A specific case of time restrictions are off-hour delivery programmes (Holguín-Veras et al. [33]; Mousavi et al. [40]). These strategies regulate access in terms of space or time. However, once the vehicles have accessed the zone in which they want to deliver freight, they need to use delivery bays to complete their operations.

Besides, the sustainable mobility options have become widespread in cities, as shown by the Sustainable Development Goals that, in its 11th one, pushes to *make cities and human settlements inclusive, safe, resilient and sustainable* (Agenda 2030). Starting from this international address, the International and National bodies defined their sustainable mobility strategies (e.g., *Sustainable and Smart Mobility Strategy* by European Commission; EC [29]), and promoted guidelines for improving urban planning (e.g., Sustainable Urban Mobility Plan – SUMP - and Sustainable Urban Logistics Plan – SULP). In this context, the new challenge of urban planning emerges i.e., to find solutions that can reduce the impacts of urban freight operations without penalizing the city life (sustainable city logistics solutions/measures). Referring to the large literature on city logistics (ex-ante and ex-post) measure assessment (De Marco et al. [23]; Croce et al. [21]; Russo and Comi [47], and references quoted therein), one of the more promising measures both under the point of view of freight operators and city users is the management and control of delivery operations (Baudel et al. [7]; Comi et al. [15, 16], Letnik et al. [38]). In fact, aiming to contain the time for delivering, freight vehicles usually park as close as possible to their customers, neglecting if no dedicated areas are available. Then, parking on-street or on double lanes reduces road capacity, delays traffic and increases interferences with other city vehicles impacting on city sustainability and liveability. Usually, cities manage such deliveries through the implementation of time windows for loading and unloading operations neglecting that it is crucial to assure that operators can find free and available spaces close to their customers. The opportunity to move deliveries towards off-peak hours is a reasonable and effective action, however the unavailability of well-located areas for such operations do not avoid the usual malpractices. Then, the opportunity to provide operators with available spaces for loading and unloading operations and tools for optimizing their tours derives (Russo and Comi [47]). Therefore, the first objective of the paper is to identify, from the extensive literature on delivery bay system planning, management and control, the main criteria for classifying them, focusing on the implementation process, system sizing (supply and demand), operations control rules and use of telematics applications that could support their booking and location (Section 2). Subsequently, due to the desirability to have methods and models for ex-ante assessment, the second macro-objective of the paper is: to identify the methods and models that can be used in the ex-ante assessment of delivery scenarios to evaluate the location and sizing of delivery bays (Section 3). The benefits of using the proposed methodology are thus evaluated through a real case study developed for the inner area of Santander (Spain; Section 4). Therefore, the third objective of the paper is: to identify the optimal delivery system according to better location and sizing delivery bays taking stochasticity of the system into account. The obtained results are thus discussed in Section 5, while Section 6 sets out the main conclusions and draws the road ahead.

2. The background

As pointed out earlier, the new challenge facing urban planners is to find solutions that reduce the impact of urban freight mobility without penalising city life. For such measures to be successful, it is important that it is accepted by all involved stakeholders, namely, urban supply chain operators (i.e., freight wholesalers and distributors, carriers, small, medium and large retailers). Acceptability for these players must be considered, in addition to their attitudes towards new distribution policies (Domínguez et al. [28]). Surveys have recently been carried out in two Spanish cities on two different distribution policies: off-hours deliveries and the use of urban distribution centres. The results showed that delivery recipients prefer to not change the manner in which they receive deliveries (Dell’Olio et al. [26]). Therefore, the solution of improving delivery bays may succeed in improving urban freight transport, given that this solution does not require receivers to revise their delivery process.

Private and freight vehicle users compete for parking in city centres, where public space is scarce. There is a relationship, researched by Wenneman et al. [50], between delivery bay demand, delivery bay supply, and the number of freight vehicles that park illegally. One of the problems related to delivery bays in cities is that, in many cases, parking supply is lower than demand by carriers (CERTU [10]; Alho and e Silva [2]; De Oliveira and Guerra [24]; Letnik et al. [38]). In consequence, freight vehicles double-park along the street or at intersections to load and unload (Ezquerro et al. [30]). Congestion and therefore pollution increase, mainly during peak hours. Double-parking entails a cost for transport operators due to the possibility of being fined and, moreover, they in turn are affected by congestion (Ezquerro et al. [30]).

Browne et al. [9] compared the measures applied to delivery bays in Paris and London. In Paris, they focused on managing the allowed time for delivery operations and enacting parking and loading regulations, whereas in London, they focused on training carriers and dialogue among carriers, traffic authorities, consumers and local residents about problems during deliveries.

Danielis et al. [22] asserted that many carriers do not use delivery bays due to the high percentage of vehicles illegally parked in such spaces. In Bologna (Italy), a research study carried out on delivery bays in the limited traffic zone (LTZ) showed that more than 50% of delivery bays were illegally occupied while the surveys were being carried out (Dezi et al. [27]).

Others measures to improve the situation focus on delivery bay booking systems for freight and service vehicles. McLeod and Cherrett [39] studied this measure, in which users can book a delivery bay on a street in Winchester (England) in advance. A monitoring system, in other words the use of intelligent transport systems (ITS) (Patier et al. [43]), is necessary to ensure its efficacy. The BESTFACT project uses new technologies; I-Ladezonen case (BESTFACT [8]) monitors delivery bay occupancy to know whether they are occupied by freight vehicles or cars. Another step forward is the monitoring of delivery bays in real time, as used in the DynaLOAD project (Comi et al. [17]). This project aims to optimise the use of delivery bays in real time. In addition to offering suggestions on delivery routes, this system allows logistics operators to book delivery bays (Comi et al. [15, 16]).

In the urban planning process (Ambrosino et al. [3]; Russo and Comi [44]), city authorities need to determine how many delivery bays should be available for freight distribution, as well as their specific location in the road network (Dezi et al. [27]). Aiura and Taniguchi [1] determined the optimal location of delivery bays and minimised the total costs of both freight vehicles and passenger cars but assumed that the number of delivery bays is fixed. Authorities must also determine a strategy through the implementation of measures or regulations in order to promote their appropriate use.

The aforementioned research studies on measures and strategies used have been summarised in Table 1. The aim of these studies was to improve urban freight transport and the use of delivery bays based on the

Table 1
Summary of the main researches in the field of delivery bays (DB).

Criteria	References
Different measures on DB	Anderson et al. [4]; Browne et al. [9]; Comi et al. [18]; Delaître and Routhier [25]; Holguín-Veras et al. [33]; Russo and Comi [46]
Stakeholders and their behaviour in DB	Domínguez et al. [28]; Dell’Olio et al. [26]
Supply and demand of DB	Alho and e Silva [2]; De Oliveira and Guerra [24]; Wenneman et al. [51]; Letnik et al. [38]
Illegalities in DB	Danielis et al. [22]; Dezi et al. [27]
Delivery bay book systems	McLeod and Cherrett [39]; BESTFACT [8]; Patier et al. [43]; Comi et al. [15-17]
Optimal location of DB	Aiura and Taniguchi [1]; Dezi et al. [27]; Muñuzuri et al. [41]; Tamayo et al. [49]

existence of a number of delivery bays (DB) located at different points around the city.

The literature above reviewed shows that some efforts have been done for improving loading and unloading operations in cities, however further studies should be performed for assessing delivery bay supply, taking the dynamism and stochasticity of the urban environment into consideration.

Therefore, the literature reviewed has convincingly shown that operative, disaggregate and dynamic procedures for planning delivery bay systems in urban area mainly follow an average and static approach. Therefore, given the dynamism and the stochasticity of transport networks (Kessler et al. [37]), and to provide an answer to the emerging needs from the fast-evolving urban transport system, this paper proposes a methodology for delivery bay supply design that optimises the time spent loading and unloading by operators and reduces the negative impacts of deliveries on traffic. The methodology, as described in the following Section 2, consists of two main steps:

- (1) Initial/tentative measurement; thanks to queueing theory, we can first estimate the necessary number of delivery bays. This stage becomes very important when no delivery bays are present in the study area, or when the study area is very large and the pre-

identification of a set of zones on which to focus could be useful for limiting time spent on research;

- (2) Verification through simulation; due to the limitations of queueing theory with regards to the dynamic character of the process with a lot of interacting entities. In this step, many important delivery characteristics will be disaggregated and applied (e.g., delivery time depends on the vehicle used, freight types and so on) and the system will be simulated.

3. Methodology

This paper presents a methodology for verifying and/or planning the optimal number of on-street delivery bays in a city. The objective is to plan for the necessary number of delivery bays so that carriers can have reserved areas for completing their delivery operations. They allow operators to avoid long waiting times or illegally-parked freight vehicles. The latter results in a decrease in road capacity and therefore delays for all vehicles, including freight vehicles themselves. Secondly, there is a possibility of fines for carriers. Pedestrians are also affected by freight vehicles if they are badly parked on the sidewalk. In particular, as emerged from road accidents analysis, there is a significant number of accidents involving pedestrian and commercial vehicles with high economic costs (Russo and Comi [45]).

As said, the aim of the proposed methodology is to provide the number of delivery bays (DB) necessary for freight vehicles to always have a free and available space or a short waiting time to be able to carry out their delivery operations in the dedicated spaces. The zone where this methodology could be applied must be small enough to ensure that all customers within the zone are easily reachable by foot from any delivery bay.

The methodology is carried out in two stages. In the first stage, an initial estimation of the number of delivery bays necessary is made using queueing theory. The results of this first stage are applied in the second stage in order to obtain and verify the optimal number of delivery bays in a more realistic way. To that end, a discrete event simulation programme has been used given its capacity to cope with the arrival distribution of freight vehicles for all time frames, as well as different delivery times according to the type of freight (Fig. 1). In fact,

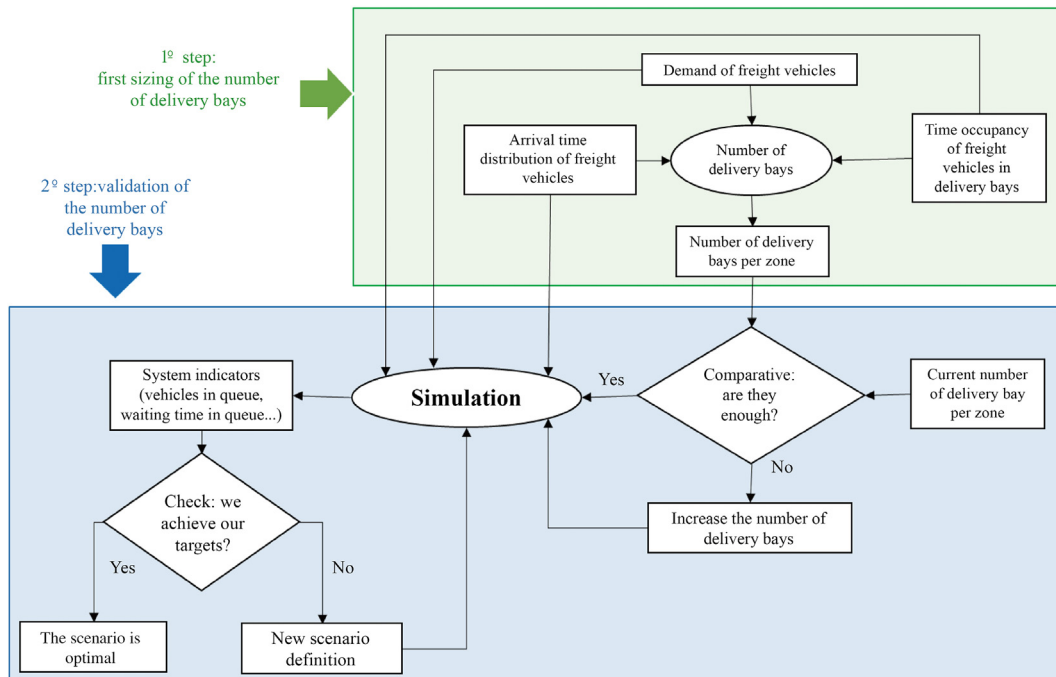


Fig. 1. The proposed two-stage methodology.

according to the freight type, time spent for delivering can be significantly different.

3.1. First stage: initial estimation sizing

In this first stage, an initial dimensioning of the number of loading and unloading zones is carried out based on queuing theory (Sundarapandian [48]). Queuing theory is used in numerous transport areas. Ibeas et al. [34] applied it to study how on-street parking manoeuvres and badly-parked vehicles influence traffic flow, and linked the reduction in link capacity for each case in the study with the increases in average journey times for the rest of the road users.

Queuing theory is the mathematical study of waiting lines, or queues, which are caused when the traffic demand is greater than the capacity. Kendall's notation is the standard notation system used to classify queuing systems:

$$a / b / c (d, e) \quad (1)$$

where:

- ✓ a represents the type of distribution for the arrival process:
 - D = Deterministic variable;
 - M = Random variable: negative exponential;
 - E = Random variable: Erlang;
 - G = Random variable: generic.
- ✓ b indicates the type of service configuration: with a ;
- ✓ c represents the number of channels (servers): 1, 2, ...;
- ✓ d represents the maximum number of customers allowed in the queuing system (either being served or waiting for service): (∞ , n_{\max});
- ✓ e indicates the queue discipline:
 - FIFO = First In-First Out, users served in order of arrival;
 - LIFO = Last In-First Out, users served in reverse order to arrival;
 - SIRO = Service In Random Order, users served in random order;
 - HIFO = High In-First Out, the user with the highest value of a suitable indicator is served first.

The input data required in order to apply queuing theory are the average delivery time of all freight and the number of vehicles arriving at delivery bays during peak hours. Queuing theory is the fastest way to obtain a first approximation; while it does not accurately simulate reality, it provides an estimate of the number of delivery bays required.

Queuing theory, which is only applied for peak hour calculations, utilises a $M/G/c/\infty$ /FIFO queuing model. In other words, the arrival distribution follows an exponential distribution, and the delivery time (service configuration) follows a normal distribution. As to the number of servers, in this case being the number of delivery bays, the result will be obtained by applying queuing theory (DB_{QT} , number of delivery bays using queuing theory).

The goal of this step is to obtain a first estimation of the necessary delivery bays. The results achieved using queuing theory are compared to the number of existing delivery bays in the study area in order to identify whether or not there is a sufficient number of DB .

Queuing theory has a constraint. In fact, this methodology does not closely approximate reality for two reasons: (a) it uses the same delivery time for all vehicles and (b) only one type of arrival distribution can be applied during the period of study. This is why queuing theory was applied during peak hours. For this reason, in the second stage, the validation of the number of delivery bays is carried out to approximate the reality more closely.

3.2. Second stage: validation of the number of delivery bays

The number of delivery bays necessary is validated in the second stage in order to obtain an accurate number of necessary delivery bays.

To achieve this, a simulation model has been developed using the Rockwell Arena software, a discrete event simulator. The Arena programme is capable of simulating new scenarios for the evaluation of possible improvements and provision of statistical data to verify if the desired results have been obtained within the planned scenario. In other words, it can verify the changes made before implementing them. Arena is used in a wide range of applications, including traffic simulation (Kamrani et al. [36]).

Process variability and the randomness is determined by stochastic variables, which have been disaggregated and applied. The stochastic variables used are vehicles' arrivals, which allow for the process to be analysed over time, and delivery time, which changes according to the freight type. Each type of freight also changes according to a distribution function.

Based on the first stage results, the second stage results (DB_{QT}) and the current number of delivery bays in the study area (DB_C , current number of delivery bays) are compared:

- If $DB_{QT} > DB_C$, the discrete event simulation begins with a scenario in which the number of delivery bays is equal to DB_{QT} ;
- Otherwise, if $DB_{QT} < DB_C$, the simulation begins with a scenario with the number of delivery bays is equal to DB_C .

Therefore, one type of input data is the number of delivery bays. Other necessary data for scenario simulation are the arrival distribution, the freight type distributed and the delivery times for the different freight types identified.

The discrete event simulation follows the flow diagram presented in Fig. 2. The vehicles between the permitted weight limits (v) arrive at each study zone according to the previously-defined arrival time distribution. These vehicles are characterised by their type of freight, and therefore their delivery time. If the loading/unloading zone has free space (it is available), the vehicles are ready to make their deliveries. If there are no free spaces and the waiting time in queue is low, freight vehicles wait for spaces to be free. If not, vehicles do not park in the authorised areas; they double-park, park on the sidewalk or in car parks, go to another delivery bay, or choose another option.

The simulation results provide a set of indicators that change according to the simulation such as: number of vehicles in queue, waiting time in queue, number of vehicles going to delivery bays and the number of vehicles that do not go to delivery bays due to high waiting time in queue. These indicators verify whether the desired goals are achieved in the scenario simulated. If so, the optimal scenario has been achieved. If not, a new scenario must be developed until the optimal scenario is found.

This methodology differs from other possible approaches (as discussed in Section 2) in the detailed consideration of the carriers' behaviours when they do not find parking space at their desired destination. This consideration is important since it allows capturing the dynamism and stochasticity of the phenomenon to be modelled.

4. Case study

The proposed methodology has been applied in a real case study in Santander's urban centre (Spain). Santander is a medium-sized city with a population of approximately 180,000. The study area of 0.922 km² has been subdivided in 29 smaller zones (Fig. 3) to ensure useful deliveries, that is, that a carrier is able to go to a delivery bay near their final destination. The study area currently has 239 delivery bays used by carriers to serve 1,961 stores.

To apply the two-stage methodology described in the earlier Section, goods movements in the delivery bays must be known and characterised. To this end, the necessary data have been obtained from a previous study completed by some of this paper's authors (Ibeas et al. [35]; Nuzzolo et al. [42]; Comi [12]; Comi et al. [19]). Furthermore, 486 surveys have been made of 10 different delivery bays in the study area for the purpose of

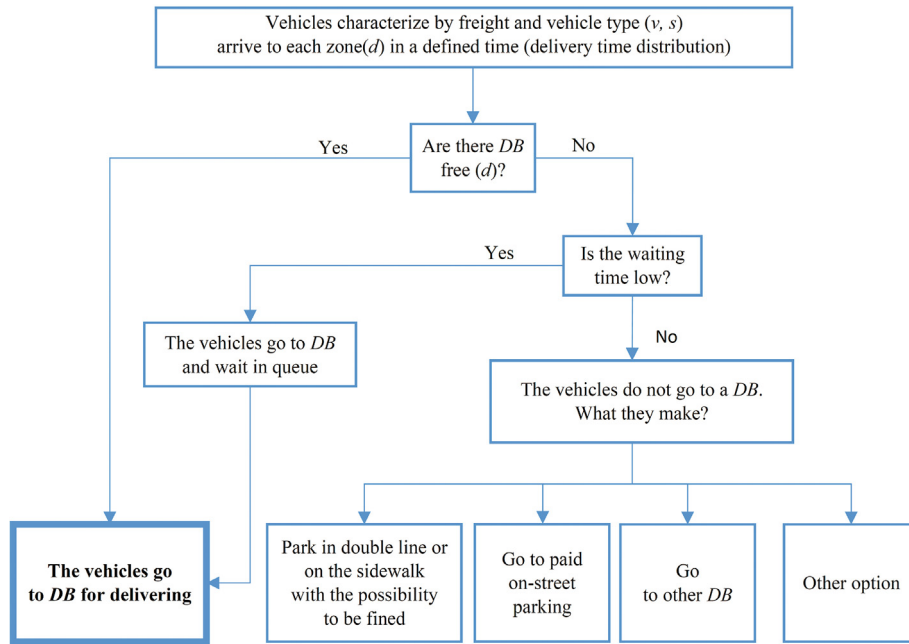


Fig. 2. The proposed discrete event simulation diagram.

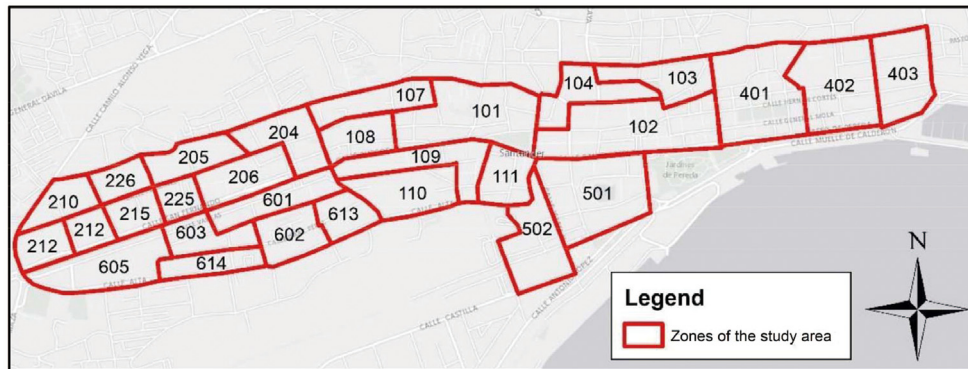


Fig. 3. The zones of the study area.

verifying information from the previous study and collecting new information, such as (1) the delivery time for each freight type or (2) the decision that vehicle drivers would take if the delivery bays were occupied. Such an info was then used, as shown below, for the estimation of the delivery time distribution by freight type (Table 2) and for evaluating the maximum time accepted by drivers for finding an available delivery bay before to illegally double-park.

Freight demand has been classified according to seven freight types (s): foodstuff, clothing, home accessories, household and personal hygiene, stationery, building materials and other goods/freight. We have

Table 2
Delivery time distribution by freight type.

Freight type	Distribution	Expression
Foodstuffs	Weibull	$0.999 + WEI(13, 0.707)$
Home accessories	Beta	$0.500 + 65 \cdot BETA(0.573, 1.870)$
Stationery	Weibull	$0.999 + WEI(11, 0.953)$
Clothing	Beta	$0.500 + 54 \cdot BETA(0.441, 0.826)$
Building materials	Beta	$16.500 + 53 \cdot BETA(0.448, 0.536)$
Household and personal hygiene	Lognormal	$0.500 + 65 \cdot LOGN(12.000, 21.800)$
Other	Lognormal	$0.500 + LOGN(23.200, 53.600)$

based our work on the attraction model developed by some authors of this paper in order to obtain the freight demand (Ibeas et al. [35]):

$$Q_d = \beta_{AD} \cdot AD_d + \beta_{ASA} \cdot ASA_d \quad (t/day) \quad (2)$$

where:

- ✓ Q_d is the average quantity of freight attracted by zone d ;
- ✓ AD_d is the total number of employees in zone d ;
- ✓ ASA_d is a dummy variable introduced in order to measure the different power of selling in zone d with high shop density. This is equal to 1 if the ratio of retailer employees to residents in the zone d is higher than 35%;
- ✓ β_{AD} and β_{ASA} are parameters calibrated for each freight type.

The number of deliveries is obtained by first calculating the quantity attracted in each zone using the above attraction model (Eq. (2)). Subsequently, the average size (e.g., weight) of shipment for each freight typology is considered (Nuzzolo et al. [42]) and the average size of delivery has been confirmed with the survey carried out (Table 3).

Then, the total deliveries attracted in each zone is calculated without differentiating by freight type, then used to verify the results obtained (Fig. 4).

Table 3
Average size of delivery for each freight typology.

Freight type	Delivery (kg)
Foodstuffs	87.7
Home accessories	43.9
Stationeries	4.2
Clothing	9.0
Household personal hygiene	34.2
Building materials	104.2
Other	42.1

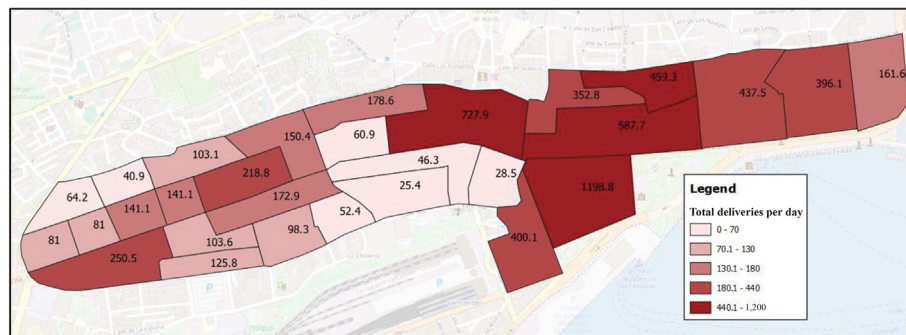


Fig. 4. Total deliveries/day in the study area.

Demand has also been classified by transport service typology (*r*): receiver on own account, wholesaler on own account, or carrier, obtaining the distribution shown in Table 4 (Ibeas et al., 2012), being ratified by the survey carried out that reported 69% of wholesaler in own account or carrier and 31% as receiver in own account.

The type of vehicle (*v*) eligible to use delivery bays is regulated by municipal authorities (Ayuntamiento de Santander, 2016 [5]). In Santander city centre, only vehicles with a gross vehicle weight rating (GVWR) of 1.8–8 tons can use loading/unloading zones from 7.00 a.m. to 2.00 p.m., for not more than 30 min. In our study area, delivery vans below 1.8 tons account for 37% of freight traffic while trucks with a GVWR of between 1.8 tons and 8 tons account for 63% (Ibeas et al., 2012). It should be noted that heavy trucks over 8 tons are not allowed to enter the study area. The arrivals distribution during the allowed time window is represented in Fig. 5.

Table 4
Distribution of transport service type for freight type (%) (Ibeas et al. [35]).

Freight type	Receiver in own account (%)	Wholesaler in own account or carrier (%)
Foodstuffs	49	51
Home accessories	25	75
Stationeries	4	96
Clothing	23	77
Household personal hygiene	2	98
Building materials	27	73
Other	50	50
Total (average share)	38	62

As said, the new survey allowed the delivery time distributions to be estimated. Table 2 reports the different functions developed according to the different freight types identified (*s*). Pearson's chi-square goodness of fit test was performed to ensure the validity of the distribution assumed (with a significance level of 5%) in all freight types.

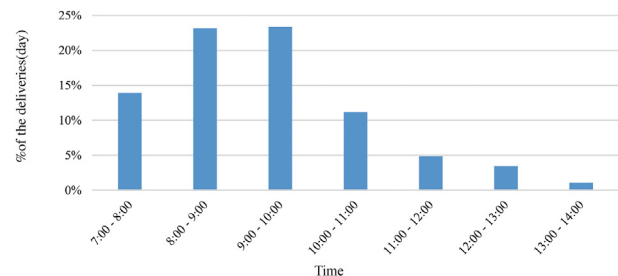


Fig. 5. Arrival time distribution (%) (Ibeas et al., 2012).

However, within each freight type, there is no difference between service typologies (*r*). In other words, the distribution of delivery times is practically assumed to be the same for the receiver on own account and the carrier, so no further characterizations have been made.

Besides, according to the survey results, the data collected showed that the probability of surpassing that maximum time allowed (i.e., 30 min) is high for some freight type due to the lack of enforcement of this municipal regulation. Despite this fact, the delivery time distribution observed has been taken into consideration because that is what is currently happening in the city. Based on all of this information, the two-stage methodology described above can now be implemented.

In addition to using the new information from the survey to estimate the delivery time distribution by freight type (Table 2), it has also been used to evaluate the maximum time drivers accept to find an available delivery area before parking at double queue illegally. This is important in the second phase of the proposed methodology. Since depending on the carriers' decisions, in a waiting scenario in the loading/unloading area, the method determines the optimal number of bays to minimize these waiting times and reduce churning traffic in search of an available delivery area.

In fact, based on the surveys made, only 16% of those surveyed would wait for a free delivery bay; the average wait time of those who are willing to wait is 8 min. The remainder of drivers surveyed would not

wait for a free delivery bay and would thus make the decision to illegally double-park or park on the sidewalk (84%), go to another delivery bay (11%), go to paid on-street parking (1%) or use another option (4%).

4.1. First stage: initial sizing

Queueing theory has been used in each zone of the study area during peak hours. As stated above, the $M/G/c/\infty/FIFO$ model is applied using queueing simulation software.

The arrival distribution follows an exponential distribution, $Exp(\lambda)$, where λ is the average number of arrivals per unit time; this changes for each zone depending on the total number of deliveries attracted during peak hours. Furthermore, it is assumed that the delivery time follows a normal distribution with mean of 15 min and a standard deviation of 5 min for all the identified freight types, given that distinctions between typologies could not be applied in queueing theory.

In addition, and as previously mentioned, a restriction on waiting times is applied: freight vehicles do not wait more than 1.2 min in queue, because if carriers have to wait longer, they decide to double-park or park on the sidewalk. This behaviour was revealed during the survey with truck drivers earlier introduced.

The difference between the number of delivery bays obtained by applying queueing theory for 50 replications and the current number of delivery bays is shown in Fig. 6. Each zone has been represented in green if there were fewer delivery bays in the preliminary dimensioning than the current scenario (current excess of DB). Warm colours – yellow, orange and red-were used for the opposite case (current lack of DB).

to obtain an accurate number of delivery bays necessary in each zone.

4.2. Second stage: validation of the number of delivery bays

In this second stage, a discrete-event simulation has been used to simulate new scenarios so as to evaluate possible improvements and verify whether the desired results are obtained with the planned scenario.

Multiple scenarios have been simulated for each of the 29 zones, with 100 replications for each one. As mentioned before, in the first simulation scenario, the number of delivery bays is equal to:

- ✓ The current number of DB, if $DB_{QT} < DB_C$;
- ✓ The number of DB obtained using queueing theory (first stage), if $DB_{QT} > DB_C$.

We obtain result parameters from this first simulated scenario including: the distribution of the number of vehicles in queue, the distribution of the waiting time in queue, the number of vehicles that go to DB without waiting, the number of vehicles that do not go to DB because the waiting time is high, etc. With all these parameters, we are able to verify whether or not we have achieved our objectives through this scenario. If the desired goals are achieved, the optimal number of DB has been found. If not, a new scenario is designed by changing the number of DB until the optimal number is reached.

For example, the results obtained in zone 501 (Fig. 3) of the study area are shown in Table 5. This zone has been selected because during the

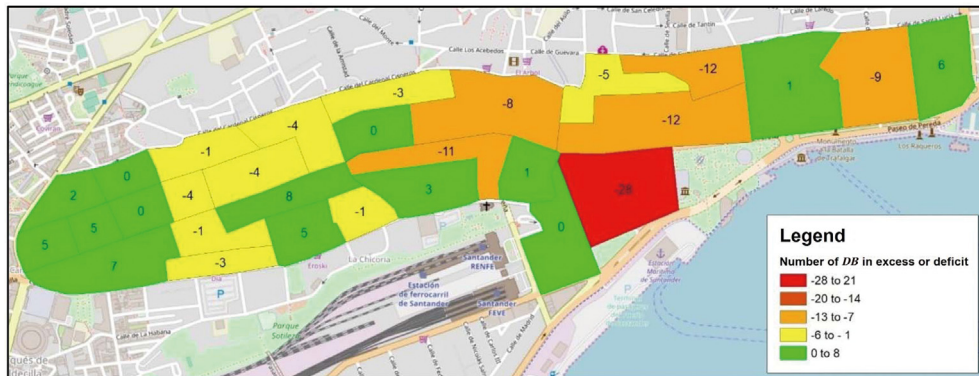


Fig. 6. Number of delivery bays excessive or lacking compared to the current number when applying the methodology during peak hours.

Excess or lack of delivery bays between border zones is also evaluated. Their difference should be examined to determine whether data collection was bad, for example, including the use of a delivery bay located in one area that serves stores located on the border of another area. In this case, the current number of delivery bays in those zones has been increased or decreased as appropriate. Fig. 6 shows the results of this verification. However, there are still border zones with excesses and deficits. This could be due to a not-optimal spatial distribution of the delivery bays. An example of this is visible on the right side of Fig. 6, where one of the zones has a deficit of 9 DBs (zone 402) and the border zone has an excess of 6 DBs (zone 403). In Fig. 6, we can see that, according to this first estimate, 10 of the 29 zones have more delivery bays than necessary and 4 zones have the exact number needed (represented in green). On the other hand, zones lacking delivery bays exist (warm colours). One, in particular, has a deficit of 28 DBs.

The aim of this first stage is to obtain approximate results in terms of the number of delivery bays needed. These results will turn into input data for the second stage, during which we will carry out a more realistic simulation

first stage, its result had the greatest difference with the current scenario. In this zone, $DB_{QT} > DB_C$; therefore, the first simulated scenario begins with $DB = DB_{QT}$. Various scenarios continued to be simulated until the optimal scenario was achieved, with the following results:

Table 5 Results from zone 501.

	First simulated scenario	Optimal scenario
Number of delivery bays	44	50
Number of deliveries per day	1,199	1,199
Nº of vehicles that go to DB to make delivery operations without waiting	391	538
Nº of vehicles that go to DB and wait in queue	164	70
Nº of vehicles that do not go to this DB because the waiting time is too long	54	0

The distribution of the waiting times in queue can be also obtained from the simulation (Fig. 7). In this figure, we see the most critical moments, during which waiting times are close to 1.2 min. These moments are essential for sizing the zone.

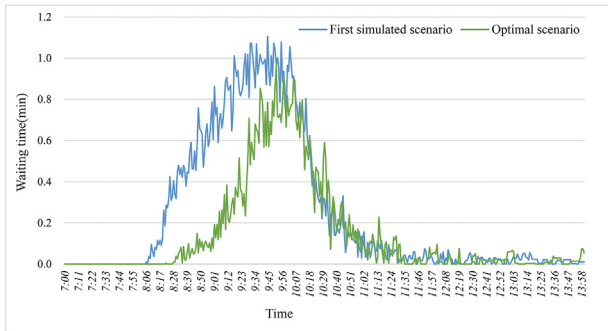


Fig. 7. Waiting time in queue distribution in zone 501.

From the results obtained, we can observe that the number of DB required is greater than the number obtained according to queueing theory because the discrete event simulation more closely approximates reality. Furthermore, it can be observed that the critical time period is between 9.30 a.m. and 10.30 a.m.. In addition to reducing the duration of the critical period, this occurs 1 h later than in the first simulation scenario (with equal distribution of arrivals). Therefore, the solution finally obtained is much more efficient and adapts better to the time distribution of arrival in the area (Fig. 5).

This same procedure has been carried out in all the 29 zones of the study area. The optimal number of delivery bays in the whole study area is 282, whereas 239 delivery bays are currently available. The optimal number of delivery bays for each zone of the study area obtained using the methodology described in this paper is represented in blue in Fig. 8. The difference between the optimal number and the current number of delivery bays is also shown. It can be observed that in the Western zone of the study area, fewer delivery bays are required; this difference with the current scenario varies between -5 DB and +7 DB, meaning that some zones currently have an excess of up to 5 delivery bays and others have a deficit of 7 delivery bays. On the other hand, in the Eastern and central zone, more delivery bays are necessary due to increased freight demand. In general, there is a lack of delivery bays reaching a deficit of 34 in one of the zones.

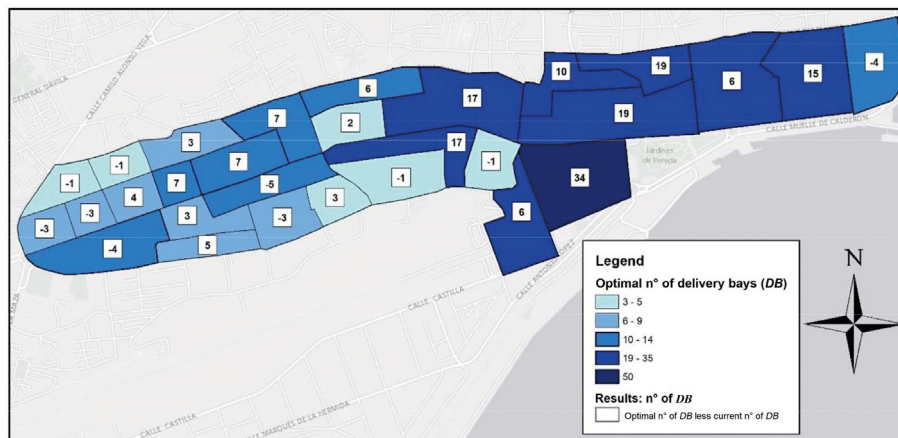


Fig. 8. Optimal number of delivery bays.

5. Discussion

Our case study has been carried out in the city centre of Santander (Spain), distinguishing between different freight types. We have obtained the results shown in the Fig. 9, where the number of delivery bays obtained is represented both during the first stage of application of queuing theory (orange line) and in the second stage with a discrete event simulation program (blue line), as a function of the number of deliveries (x-axis). On the y-axis is the number of deliveries between 7.00 a.m. and 2.00 p.m., the time window allowed. For each of the stages, a trend line shows that when the number of deliveries is smaller, the difference between the stage results continues to be small. This Fig. 9 makes it possible to directly and quickly calculate the necessary number of delivery bays in the urban centre of Santander, which may be very useful in the event of major changes in freight demand, such as the opening of a shopping centre, on the condition that the changes in arrivals distribution and freight types are not large.

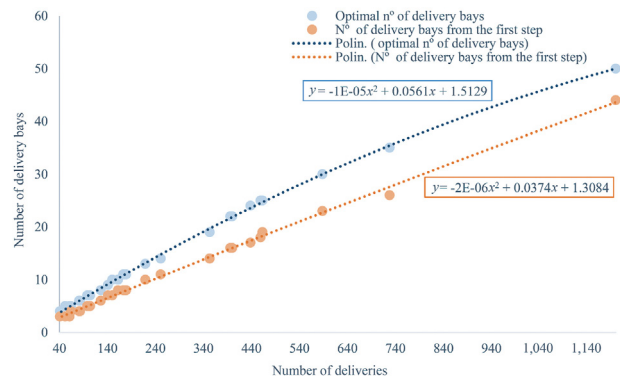


Fig. 9. Optimal number of delivery bays vs. number of deliveries from 7:00 to 14:00.

Beyond the direct applicability to the case of Santander, the results obtained could be extrapolated to other cities with characteristics like Santander. To the same extent, there are data that either confirm such similarity or that serve to calculate the input parameters of the proposed methodology. Many cities use to collect traffic counts (both of private and commercial/freight vehicles) and to carry out surveys with passengers and freight operators for obtaining an aggregate overview of city

mobility. Then, the main effort to apply this methodology refers to detail the info from transport and logistics operators, in particular, to point out the origin and destination of delivery tours, the arrival time distribution and the time occupancy of freight vehicles in delivery bays. Additionally, the carriers' behavior should be characterized in the situation of not having parking space and of making a decision (i.e., to wait, to park illegally, of going to another delivery area, etc.)

The results of the simulations made for the proposed scenarios show the significance to use such a tool. In fact, the use of a system that provides the optimization of delivery bay system can help to reduce total delivery time spent on queue as well as to reduce the number of double parking spaces for deliveries, less congestion and pollution, and an improved image of the city. It should be noted that, today, cities represent in Europe more than 85% of gross domestic product, and as a result, cities are experiencing a growing demand for transport with increasing congestion, noise, emissions, and other negative effects of transport on the environment and city dwellers. These issues increase in the historical and inner areas which are characterised by narrow streets and a high competition between private and commercial spaces for parking. Besides, in the next future it is expected that the cities will face with some important issues related to following changes: small and frequent shop deliveries (due to limited availability of retail store surfaces in the inner areas due to high rent costs and just-in-time policies); e-commerce and omni-channel retailing (in particular, in the era post covid-19 pandemic); new way to deliver products to customers: express delivery, same-day delivery, as well as instant-deliveries. This leads to an increase in the number of commercial tours and low load factor of freight vehicles. Several studies pointed out the high contribution to unsustainability given by goods movements and logistics (Letnik et al. [38]; Russo and Comi [46]; and references quoted therein). Besides, the simulation showed that the current delivery bay locations is not optimal. In the base scenario, the maximum number of vehicle servable were 259 with averagely 11.26 vehicles for delivery bay. Such a study can also provide some managerial insights and guide the reorganization of the urban spaces taking into account that freight transport represents a high component of urban mobility and allow area to live. In particular, the city administrators and city planners could have a lever to increasing of delivery bays and their location according to demand and the real features of the delivery system. In this way, city users can benefit from the reduction of vehicles parking in not-allowed spaces, the possible reduction of the interferences with other road users with social benefit (i.e., improvement of road safety).

5.1. Extension of the proposed methodology

In the proposed methodology, the necessary number of delivery bays is calculated for the zones in the study area. These zones are small enough to ensure that a freight vehicle will park close to its final destination. But this methodology can be improved upon if the exact location of delivery bays is calculated.

The data collection process is especially important since the results obtained can only be as realistic as the data provided. In the Santander case study, the collected data are aggregate data for the 29 zones of the study area. The percentage of each freight type, the percentage of each type of vehicle, the arrival time distribution etc., are the same for the whole study area. Therefore, if those data were disaggregated, the results obtained would be more realistic and could be different.

Finally, future developments will also focus on improving the models (through a more extensive survey) and overcoming the exemplificatory assumptions introduced in the simulation. Besides, the extension towards the inclusion of booking/reservation. In fact, as shown in Browne et al. [9] and Comi et al. [18]), it can lead to optimized delivery trips in the city centre with about 40% reduction in the number of double parking spaces for deliveries. With respect to its use for the management and control of the delivery operations, future research will investigate the calibration of individual tour utility

models and the learning process, and test the instruments providing real-time suggestions to transport and logistics operators (Comi and Russo [13]). Such tools may constitute effective support both to transport and logistics operators, and city administrators as well. While the time spent on freight operations as well as delivery costs can be reduced, from the city administrators' perspective, this research can provide the right number of delivery bays and hence reduce interference with other city mobility components, as said, thereby improving city sustainability and liveability.

6. Conclusion

This paper proposes a methodology for obtaining the optimal number of delivery bays in order for carriers to have free delivery bays or low waiting times in queue for using the delivery bays.

The proposed methodology has two stages. In the first stage, the queueing theory is implemented to obtain a first "estimation" of the number of delivery bays needed, which will be used during the second stage. The second stage addresses variability and randomness of vehicle arrival and delivery times by means of discrete event simulation in order to obtain the optimal number of delivery bays in a realistic manner.

In the Santander case study, the proposed methodology shows that the number of delivery bays is not optimal in any of the 29 zones, and as a consequence, carriers illegally double-park, park on the sidewalk, or choose other options, or the delivery bays are never full rendering the public space useless.

With this methodology, the optimal number of delivery bays in each zone is known. By changing the number of delivery bays, we achieve the following: if the number of delivery bays is increased through this methodology, carriers will always have a free and available delivery bay, something that, at this point, never occurs. On the other hand, if the number of delivery bays decreases, the excess space that was previously used by the transport and logistics operators (e.g., carriers) could now be used by private cars for parking or to increase the sidewalks used by pedestrians. This methodology can be used in any urban area to verify whether the number of available delivery bays is optimal or to design a number of delivery bays in an urban area where this type of reserved zone does not yet exist.

Declaration of competing interest

The authors declare no conflict of interest.

CRediT authorship contribution statement

Antonio Comi: Conceptualization, Methodology, Review & editing, Supervision; José Luis Moura: Methodology, Review & editing, Supervision; Sara Ezquerro: Methodology, Formal analysis, Data curation, Writing.

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