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Quantifying parking conflicts of (un)loading bays' usage in Santiago´s CBD, Chile

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Abstract

In historic city areas and Central Business Districts (CBDs) freight dedicated (un)loading spaces are of interest because of the intense freight delivery activities in such areas and arising conflicts with pedestrians and other vehicles. This article develops a first step towards an integrated assessment of parking conflicts by calculating the potential impact an optimized (un)loading bay system in the CBD area in Santiago de Chile can achieve compared to the existing one. For this purpose, a simulation scenario has been set up using the MATSim extension package Jsprit. Therefore, data on parking behavior of commercial vehicles on a selected one-square kilometer in the historic center of Santiago de Chile has been analyzed and two simulation cases have been generated. The results indicate that contribution of different operational measures (service duration, number of deliveries per vehicle) alleviate the parking problem in Santiago´s CBD. In addition, optimizing the (un)loading bays in size leads to improvements across the assessed key indicators (occupancy rate, conflict time of occupation, waiting times).

Keywords: CBD; freight parking; (un)loading bays; Santiago de Chile; simulation; Jsprit

1. Introduction

The global trends towards increased population, growing urbanization and the sustained economic growth of cities leads to increased good distribution in urban areas. Furthermore, there is a particularly high economic pressure towards concentration in core city centers. Especially the Central Business Districts (CBDs), where parking opportunities for (un)loading processes are limited, are considered being one of the major destinations for goods pick-up and delivery (Nourinejad et al. 2014). Thus, research results related to this realm are of a great value since urban freight transport accounts for a significant part of predominant issues such as congestion, pollution, safety and noise impairing the quality of life of the city´s citizens.

In general, there are two main approaches there to relieve the competition for freight dedicated parking facilities for (un)loading processes: One approach focuses on improving the supply of parking facilities through infrastructure investments and another approach focuses on influencing the freight parking demand through policies and regulations to achieve a more efficient use of the existing infrastructure as part of parking management (Dalla Chiara & Cheah 2017). In order to support the first approach, policy makers provide guidelines and regulations for the construction of adequate freight parking infrastructure, such as, for example, the establishment of at least one (un)loading bay for every 100 m on city streets is suggested in Paris (Chen, Conway & Cheng 2017; Dalla Chiara & Cheah 2017). This approach, however, is difficult to implement in city centers due to the scarce availability of space. The second approach consists of implementing urban logistics policies and regulations to foster sustainable logistics practices (Dalla Chiara & Cheah, 2017; Holguín-Veras et al. 2015). However, both approaches, the design of freight infrastructure and city logistics initiatives, rely on the availability of data and data-driven models that are able to estimate the potential impacts and guide the decision-making process (Dalla Chiara & Cheah 2017).

Therefore, freight parking issues have been investigated in many cities around the world, including the CBD in Santiago de Chile, where a survey of freight vehicle parking behavior has been conducted on a selected one-square kilometer. To investigate the parking demand based on the provided data, three necessary inputs were given: number of trips attracted by each establishment type, the number of establishments and the duration of parking, whereby the supply is equal to the amount of available (un)loading bays in the study area. Hence, it is aimed to investigate to what extent parking conflicts can be quantified with the capabilities of the simulation tool used and to what extent changes in size relieve the competition for freight dedicated parking facilities to (un)load in Santiago´s CBD in order to aim the sustainable goals of the city.

The article is organized as follows: first a literature review on commercial vehicle parking management is presented (section 2). In the methodology section, the methodical procedure of the simulation is described (section 3). Section 4 summarizes the main input needed to perform the simulation, which is followed by the analysis of the simulation results that are represented in two reference cases, both of which are aiming at analyzing

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parking conflicts and optimizing the performance of (un)loading bays in the study area (section 5). Finally, under conclusions, the main findings of this research are discussed and suggestions for possible future research are provided.

2. Commercial vehicle parking management

Urban freight transport research underlines, among the different policy options available, the importance of (un)loading related policies. The research on commercial vehicle parking management can be divided into the following categories: (1) time restrictions; (2) pricing strategies; (3) spatial arrangement of (un)loading bays; (4) intelligent information and control systems; (5) parking enforcement and (6) parking simulation. These categories are explained in the next sections.

2.1. Time restrictions

Many cities respond to the challenge of generated parking conflicts during peak time by implementing time restrictions in order to shift freight deliveries to off-peak periods of passenger traffic in order to separate the parking competition between commercial and passenger vehicles in urban areas temporally rather than spatially (Nourinejad et al. 2014). Such regulations have various designs: Either the restrict vehicle access or they restrict stopping for (un)loading processes.

In Santiago´s CBD, time regulations are applied to the on-street freight dedicated parking facilities for (un)loading activities from 7 am to 7 pm, at which delivery vehicles are not allowed to deliver to retailers and shops. However, off-peak deliveries are not being practiced by the several freight operators as shown in the collected data provided and the works of Cuevas and Giesen (2015). In conclusion, the freight parking problem in Santiago de Chile goes hand in hand with the weak institutional control mechanisms, since the applied time restrictions of deliveries to off-peak periods of passenger traffic is being violated.

2.2. Pricing strategies

Pricing strategies try to encourage a greater turnover of passenger as well as commercial vehicles with respect to increase the parking chances. In general, parking fees can be differentiated ***spatially*** (cordon-based pricing of road usage, area-based pricing schemes of infrastructure, distance dependent pricing as well as parking facility-based pricing) and ***temporally*** (Dörnemann 1998).

In Latin America, there are currently three ongoing processes for creating schemes of ***geographical demand-based pricing*** in São Paulo, Santiago and Bogotá (Steer Davies and Gleave 2009). However, acceptance of this policy is generally difficult to obtain and the system costs are considerably high, although such congestion charges have been implemented in several cities around the world, most notably in Singapore, London, and Stockholm, where this policy instrument has had positive effects in the short-, medium-, and long-terms and has generated significant revenue for these cities (City of Stockholm 2006; Inter-American Development Bank 2013; Steer Davies and Gleave 2009).

In regards to the ***temporal-based parking pricing***, the fee for an individual parking space might depend on total parking time as follows (Dörnemann 1998):

- *Fixed-rate pricing per unit time*: regardless for how long the vehicle is parked, the parking fee being charged is constant over a specific period of time. In Washington DC for example, the District Department of Transportation (DDOT) has installed loading zone meters in response to the use of loading zones for all-day parking of commercial vehicles that charge commercial vehicles $1 per hour and allow a maximum parking time limit of 2 hours (Better Market Street 2011; Nourinejad et al. 2014).
- *Progressive parking pricing*: with the increasing amount of parking time, the parking fee per unit time increases as well. The New York City Department of Transportation (NYCDOT) has implemented a pilot program to address (un)loading issues in New York. This program replaced unpaid commercial parking with hourly metered rates applying an escalating pricing rate structure of $2 for 1 hour, $5 for 2 hours, and $9 for 3 hours (Better Market Street 2011; Kaufman et al. 2012). This pricing approach has led to considerable reductions of dwell times, which has fallen from 160 to 45 minutes, with only 25 % of all commercial vehicles parking in the same space for more than one hour, which highlights the positive impact of different hourly pricing combinations (Better Market Street 2011; Kaufman et al. 2012; Nourinejad et al. 2014).
- *Digressive parking pricing*: with the increasing parking duration, the parking fee per unit time is decreasing; and
- *daily pricing*: the vehicle can park for a special price for the whole period of time of charge.

In addition, the parking fee can vary according to other factors influencing the demand for parking:

- *time of day*: identifying peak parking demand patterns by geographic areas and applying variable parking rates based on broad 'time windows';
- *day of week*: considering the differences in demand patterns between weekdays and weekends and adjusting rates based on parking demand; and
- *presence of a special event*: addresses specific issues associated with large events impacting adjacent CBD or neighborhoods (Dörnemann 1998).

The combination of several fixed-rate pricing strategies per unit time that has been successful in terms of balancing the demand and supply of parking facilities is the SF*park* program in San Francisco, which dynamically adjusts the prices of on-street parking spaces as well as off-street parking facilities, with the goal of creating available on-street parking. It means that in SF*park* pilot areas, meter rates vary based on *time of day* and *day of week* and additionally over *time of day* based on changes in parking demand using the occupancy data provided by the parking space sensors (SFMTA 2011). The evaluation of SF*park* has reported a decrease of occupancy of on-street parking facilities after several parking prices increases that has led to a balance between demand and supply of on-street parking facilities in different blocks within San Francisco (Pierce and Shoup 2013). However, freight delivery vehicles tend to avoid parking fees and thus, it is identified as an effective tool to encourage off-hour deliveries (Jaller, Holguín-Veras & Hodge 2013).

As can be seen in the examples presented in this section, the amount of parking fees varies from city to city and thus, no generally valid regulation on the amount of parking fee can be identified.

2.3. Spatial arrangement of (un)loading bays

In most cities, however, freight delivery vehicles share the available parking facilities with passenger vehicles or they perform the delivery on the road. Alternatively, there is the possibility to create freight dedicated parking spaces called loading bays. The spatial configuration of (un)loading bays refers to the size, number, position and usage of such parking facility for commercial vehicles operations to improve freight delivery operations. As it is for size and position, the city of Washington DC, for instance, has increased (un)loading bays from 40 to 100 feet (Better Market Street 2011; Marcucci, Gatta & Spaccia 2015).

Apart of increasing the size of (un)loading bays, another spatial arrangement can also be seen as an alternative option to improve the usage of the parking infrastructure. Dezi, Dondi & Sangiorgi (2010) deduce from the different types of commercial vehicles commonly used for deliveries in urban areas the spatial arrangement of (un)loading bays. As can be seen in Figure 1, the occupation of the parking lots by one commercial vehicle can be realized on three types of (un)loading bays: parallel, 30° or 90° with a total length of 7,0 m and a width of 2,5 m.

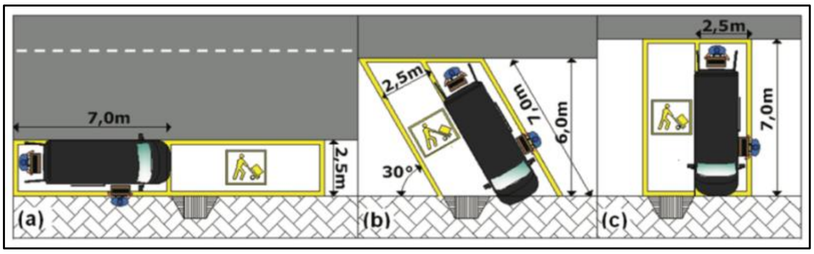

Fig. 1. Type of parking lots: parallel (a), 30° (b), 90° (c)

As it is the case for Santiago, the freight dedicated parking lots are realized parallel as presented in panel (a) of Figure 1. However, the major concern is the scarce supply of such parking facilities (Cuevas & Giesen 2015). Especially, because the Integrated Mobility Plan for Santiago de Chile includes the removal of on-street parking facilities, which also are used by delivery vehicles (Municipality of Santiago 2015). Due to the reorganization of public space in Santiago´s city center, the ranking of infrastructure projects has been defined based on sustainability and financial aspects that have led to a hierarchical structure giving pedestrians the highest priority, followed by cyclists, public transportation, freight transport and lastly to private motorized vehicles. However, apart of the reorganization of parking facilities, freight transport and infrastructural projects related to it have not been further considered in the Integrated Mobility Plan.

2.4. Intelligent information and control systems

Pricing parking lots and (un)loading bays is one possibility to manage demand in order to avoid vacancies or overcrowding. Information is another possibility to achieve steady utilization and thus, to reduce illegal parking, waiting time and/or search traffic. In addition, Information systems can be combined with intelligent pricing.

A pilot study in Toyota City (Japan), for example, made it possible for truck drivers to reserve remotely monitored parking spaces in advance of their arrival by cell phone (Marcucci, Gatta & Spaccia 2015; PIARC

2012). However, McLeod and Cherett (2011) investigated the concept of a managed and in advance bookable (un)loading bay system for the city of Winchester for the use of delivery vehicles with the intention to evaluate the benefits that occur from using such. The results demonstrate that in advance bookable (un)loading bays can be combined with pricing strategies and may improve freight delivery behavior and reduce problems associated with parking as long as delivery drivers arrive in time for bookings.

Furthermore, improvements in parking technology offer significant opportunities for analyzing and sharing data in order to use the existing infrastructure as efficient as possible. Thus, cities tend to use overlapping technologies such as parking meters, pay-by-phone and license plate recognition technology that may increase data availability and facilitate the process of integrating parking payment and enforcement systems. In addition, the potential to integrate mobile devices into the reservation and payment process of (un)loading bays reduces problems associated with commercial vehicle parking behavior (McLeod & Cherett 2011).

2.5. Parking enforcement

Commercial vehicles are of interest in parking enforcement because of their heavy presence in need to perform pick-ups/deliveries and their recurrent parking violations (Marcucci, Gatta & Spaccia 2015; Nourinejad & Roorda 2016). In addition, a significant issue is also the need for law enforcement to deter non-freight vehicles from occupying (un)loading bays. A significant issue is also the need for law enforcement to deter non-freight vehicles from occupying (un)loading bays. Therefore, parking enforcement policies consist of three components: detection technology, level of enforcement and citation fine (Nourinejad & Roorda 2016). The methods for monitoring illegally parked commercial vehicles are either human surveillance (on-foot, cycling and driving officers) or video detection, such as license plate recognition software and cameras (Better Market Street 2011; Nourinejad & Roorda 2016). The level of enforcement describes the density of the enforcement units (e.g. cameras or on-foot officers) in the area and citation fine describes the imposed penalty for illegal parking (Nourinejad & Roorda 2016).

Furthermore, physical barriers can also be used to enforce delivery regulations. Physical restrictions, including roadway design, gates and permanent or retractable bollards, can be used to either impede truck access or (un)loading activities (Better Market Street 2011; Kaufman et al. 2012; Ramon 2001). These systems can be controlled using technology that allows access to permitted vehicles, such as parking space sensors/bollards.

Parking enforcement policies have been implemented in major cities for many years to successfully establish parking management programs. For example, the Los Angeles Department of Transportation (LADOT) created a parking enforcement program called ‘Tiger Teams Curbside Management Program’ to enforce parking violations during the peak travel period to reduce traffic congestion and improve the efficiency of delivery activity and therefore, deploys 15 uniformed traffic control officers and 10 tow trucks (Better Market Street 2011; Nourinejad et al. 2014). Before the introduction of the program, curb parking regulations were not strictly enforced and were often ignored (Better Market Street 2011). The implementation of the program has led to a significant decrease in the number of violators (FHWA 2017).

In New York, the NYCDOT has implemented a pilot program incorporating enforcement in 2002 called THRU Streets (NYCDOT 2004). This program consisted of THRU streets, where traffic flow was prioritized, and non-THRU streets, where accessibility was prioritized (NYCDOT 2004). On THRU streets, parking was made available on one side only with the intention of reducing illegal parking, whereas on non-THRU streets, multi-space meters were installed on both sides of the street, creating additional freight parking spaces in the study area (Nourinejad et al. 2014; NYCDOT 2004). This pilot program has led to a decrease in travel times, an increase in the network capacity, and an increase in the percentage of streets free of illegally parked vehicles.

2.6. Parking simulation

Quantifying parking spaces for freight deliveries in urban areas in size, location and number is fundamental for policy makers (Gardrat & Serouge, 2016). Previous research has shown that inadequate location or size of (un)loading spaces systems have negative impacts on traffic congestion and safety and thus different solutions to reduce the negative effects that commercial vehicles generate to people and environment need to be investigated (Aiura & Taniguchi 2006). Overall, there are five main references in the literature that tackle the issue, but they do it from different perspectives and are described in the following.

Alho, de Abreu e Silva & de Sousa (2014) present a simulation model to optimize the location and number of parking spaces. Their simulation model of urban freight operations related to the usage of (un)loading spaces requires three datasets: non-freight origin-destination matrices, an establishment-based freight survey, and an observation process for illegal parking by non-freight vehicles and legal/illegal parking of freight vehicles for assessing the impacts on congestion derived from double parking practices. Furthermore, the proposed model framework considers the location, size and number of (un)loading bays as well as correct usage enforcement in the (un)loading bays optimization process.

Dezi, Dondi & Sangiorgi (2010) discuss the subject of optimizing the (un)loading spaces in a real situation in the city of Bologna integrating both the temporal and spatial dimensions as well as the effects of the different configurations of (un)loading spaces on the urban environment. The focus of study are the size, number and location of (un)loading spaces. Alho, de Abreu e Silva & de Sousa (2014) point out that the work done by Dezi, Dondi & Sangiorgi (2010) does not provide enough information for the practical application of their methodology. Moreover, the order in which the processes is presented in their research prioritizes the optimization in terms of the size of (un)loading bays before the location of such, which is contradictory to the sustainable development goals of urban development.

Aiura and Taniguchi (2006) present a simulation/optimization model for determining the optimal locations of on-street (un)loading bays in urban areas, which can be used to evaluate the efficiency of enforcement for controlling illegal parking of passenger cars at (un)loading spaces. Furthermore, the model is focused on the minimization of the total operation costs and claim to achieve 16 % cost reduction depending on the approach to enforcement (Aiura & Taniguchi 2006; Alho et al. 2017). According to Alho, de Abreu e Silva & de Sousa (2014) the main drawback that can be found in the application of the respective model is the assumption made by Aiura and Taniguchi (2006) that freight vehicles do not park illegally, which is far from the reality in many cities (Delaître 2009; Muñuzuri et al. 2012). In addition, the authors applied their model only for one street as the type of microsimulation was too demanding (computationally and data-wise) at that time for larger geographical areas (Alho, de Abreu e Silva & de Sousa 2014).

Delaître (2009) developed a tool (DALSIM – Delivery Areas and Logistics SIMulation) that is composed of two modules: a module for the simulation of delivery areas at local level based on queuing systems, and the second one simulates the spread of obstruction on the overall flow of traffic during the deliveries based on the systems´ dynamics. However, Delaître (2009) does not take into account the situation when the delivery area is occupied by a private vehicle, which is also far from the reality and contrasting with the work of Aiura and Taniguchi (2006). Furthermore, the model cannot provide a calculation on the time lost for individual vehicles due to the temporal obstructions as well as propose an optimization for the usage of (un)loading bays (Alho, de Abreu e Silva & de Sousa 2014).

Muñuzuri et al. (2012) proposed a model for the location-selection of mini-hubs for commercial vehicles aiming at relieving the effects of time-windows constraints. This model requires a significant amount of details regarding freight traffic and is based on an extensive list of assumptions that might be too restrictive for an analysis that targets some practical applications (Alho, de Abreu e Silva & de Sousa 2014; Alho et al. 2017).

Finally, there are other relevant contributions to this field that do not necessarily address the dimensions of simulation and optimization of (un)loading bays in number, size and location. Nourinejad et al. (2014), for example, have demonstrated a micro-simulated parking choice model to investigate the potential impact of parking policies for trucks in urban areas, such as reserved streets for freight parking. Zambuzi (2015) used microsimulation (VISSIM) to model freight parking behavior, including waiting and cruising for parking and aiming to quantify the impact of delivery drivers' parking behavior to evaluate parking policies. Melo (2010) also used microsimulation to evaluate several freight-influencing policies for selected zones in Porto, Portugal, providing a comprehensive description of the factors that have led to the selection of the microsimulation software to achieve the purpose of research.

In accordance with a future-aligned integrated transport policy and planning a demand-oriented and environmentally-friendly approach of parking space policy and practice is essential as demand for parking facilities, particularly in city centers increases. Therefore, simulation-based tools to identify the potential impacts of designed policies is needed to support the decision-making process of local authorities. All the contributions previously described do not fully meet these requirements because they are either mainly concerned with the evaluation of location or size or number of (un)loading bays in the study area, but only in a very few cases research aimed at contributing to an integrated approach where both generated parking conflicts and the number, size and location of (un)loading bays are assessed. In particular, Aiura and Taniguchi (2005), Dezi, Dondi & Sangiorgi (2010), Muñuzuri et al. (2012) and Delaître (2009) focused on optimal locations of on-street (un)loading bays, while Alho et al. (2017) defined a general framework that considers both private vehicle occupation and illegal vehicles parking to evaluate the location and size of (un)loading bays.

Hence, the present article explores this research opportunity and addresses this gap by focusing on a microsimulation of commercial vehicle parking using using the MATSim extension package Jsprit that is a java based, open source toolkit for solving vehicle routing problems, through which the parking conflicts of (un)loading bays by freight operators in a selected area in Santiago de Chile, which comprises several streets, is evaluated.

3. Methodology

This section describes the methodical procedure of the simulation, which is used to assess the parking conflicts of (un)loading bays´ usage and which allows to replicate the current situation of the case study area so that an analyses of hypothetical events over time can be undertaken through which solutions for improvement of the system can be proposed. Moreover, the purpose of using a simulation tool in this work is to explain the phenomena emerging from the actions and interactions of the carriers, which correspond to delivery vehicle drivers making deliveries in the city center of Santiago de Chile.

In general, each carrier agent in this work represents a firm with a set of vehicles, a depot and a delivery plans (Horni, Nagel & Axhausen 2016). The plan contains a tour schedule for each commercial vehicle, containing planned pick-up/delivery, arrival times at the customer locations (e.g. shops) and a route through the transport network. In this work, all vehicle schedules of a carrier begin and end at the same depot outside the study area. Thus, when a simulation scenario is initialized, the carriers build a time schedule for each of their vehicles, including a route through the transport network, with delivery activities corresponding to their plans. Subsequently, all the information on the carriers´ activities at a specific time is summarized in an event file.

The methodical procedure of the simulation contains two main components of the author´s tasks. Firstly, the *parameters adjustment*, which is based on the *field data*, including all assumptions made and on the main input files needed to perform the simulation. Secondly, the *analysis* of the simulation results (carriers´ event file) leading to decide whether results make sense or not so that different scenarios can be generated.

4. Input data for the simulation

In this section the input data required to run the simulation with Jsprit is explained. The first step is to quantify the demand for parking at the (un)loading facilities. This is generated based on the data on parking behavior of commercial vehicles in Santiago´s CBD and described through the number of deliveries for each shop. Another freight parking system primitive is the parking supply, which is described through the number of (un)loading bays available for commercial vehicles. Overall, the main information of input are road network data, including the number, size and location of (un)loading bays, vehicle data and delivery data that are described in the following sections.

4.1. Data description and assumptions

The data on freight vehicles parking and delivery patterns used in this work has been collected by the *Megacity Logistics Lab* of the MIT within the *Urban Logistics Atlas* project in July 2013 (2^{nd} and 4^{th} and 5^{th} of July 2013) from 10:30 am to 8 pm. The area of study is a part of the one square-kilometer of the historic center of Santiago that is bound by the river *"Mapocho"* in the north, the street *"Alameda"* in the south, *"Cerro Santa Lucia"* in the east and *"Ruta 5"* in the west. In total, the km^2 area in Santiago encompasses 1.801 retail establishments, of which 21 % belong to the retail category *food service*, 24 % to *clothing*, 7 % *grocery* and 48 % to *others* (Merchán, Blanco & Bateman 2015). The category *others* includes establishments that do not fit in the previous categories mentioned, such as flower shops, laundry, glass stores, furniture, art supplies, sports equipment and hobby shops.

The km^2 area is marked in black in Figure 2. The 52 retail establishments for which delivery data is provided are marked in red and can be seen in a more detailed Illustration (see Figure 2). Of these 52 shops, the retail category *others* represents the highest share of establishments (37 %), followed by *food service* (33 %), *clothing* (17 %) and *drug stores* (14 %).

Additionally, a hypothetical set of (un)loading bays in the study area have been created, which is based on a recommendation of the Superintendence of Social Security *(Spanish: La Superintendencia de Seguridad Social – SUSESO)* that suggests a maximum distance between the delivery vehicle and the delivery destination should not be above 150 meters (Cuevas et al. 2017). For this reason, it is assumed that each block contains one (un)loading bay. Thus, the (un)loading bays in each block are only available for deliveries to the retail establishments in the same block. A total amount of seven (un)loading bays is located in the study area (see Figure 2).

Fig. 2. km² area in Santiago (left) and assumed locations of (un)loading bays in the study area (right)

For simplification for further work it is assumed that the information on freight vehicles´ parking behavior in the study area has been gathered at the same day. Thus, the number of retail establishments for which delivery data is provided amounts in total 71 shops. Additionally, based on the collected data, there is always one delivery vehicle per service realized resulting in 71 deliveries per day in the study area.

Table 1 summarizes the usage of all seven (un)loading bays and contains all the information needed to perform the simulation, such as the location of (un)loading bays, the number of establishments per (un)loading bay, the share of establishments (in %), the number of deliveries per (un)loading bay, the average parking duration (in hours).

Table 1. The usage of (un)loading bays.

(Un)Loading bay	Location (street name)	Number of establishments	Share of establishments (%)	Number of deliveries	Average parking duration (h)
Bay 1	Bandera	1	1,41	1	00:06:00
Bay 2	Moneda	12	16,90	12	00:09:00
Bay 3	Ahumada	25	35,21	25	00:38:00
Bay 4	Ahumada	19	26,76	19	00:09:00
Bay 5	Augustinas	2	2,82	2	00:03:00
Bay 6	Augustinas	6	8,45	6	00:04:00
Bay 7	Matías Cousiño	6	8,45	6	00:03:00

Based on the collected delivery data for Santiago, the peak time of parking delivery vehicles is from 1 pm to 3 pm with above 20 delivery vehicles per hour (see Figure 3). Furthermore, Figure 3 demonstrates the distribution of average parking duration by the hours of the day depending on the time of arrival of each delivery vehicle. Moreover, it can be seen in Figure 3 that the delivery vehicles arriving during the peak time have the lowest durations of parking.

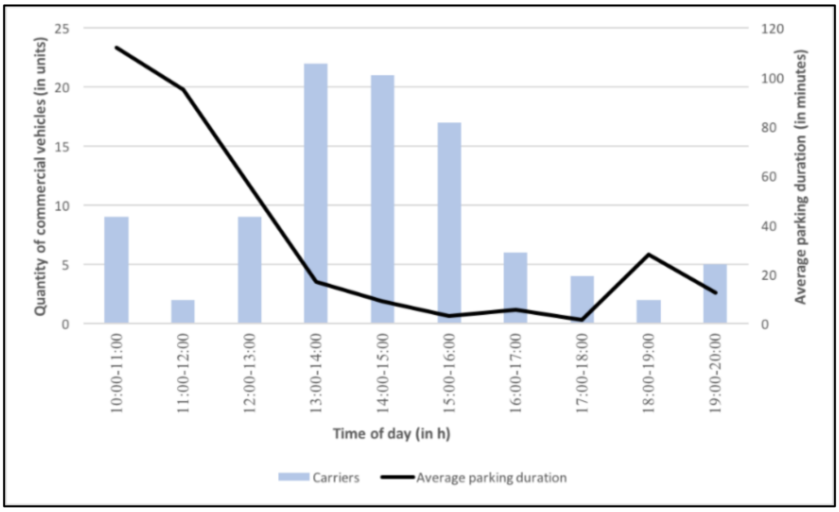

Fig. 3. Distribution of arriving parking delivery vehicles and their average duration of parking in Santiago’s CBD

4.2. Road network data

The network file is the infrastructure on which agents/vehicles can move around and consists of nodes and links.[2] Each element (node and link) contains an identifier *id*. The nodes are described by *x*- and *y-coordinate values* and the links are described by additional features: The *to* and *from* attributes reference nodes and describe the network geometry. Further attributes are traffic-related link aspects, such as the

- *length* of the link described in meters,
- the flow *capacity* of the link described through the number of vehicles that use the link per hour,
- the *freespeed*, which is the maximum speed that vehicles are allowed to travel along the link described in meters per second,

[2] The source data for the road network of Santiago de Chile is taken from the following link: https://svn.vsp.tu-berlin.de/repos/public-svn/matsim/scenarios/countries/cl/santiago/.

- the number of lanes (*permlanes*) available in the direction specified by the *'from'* and *'to'* nodes and
- the list of modes allowed on the link, as for example car, taxi, bike, etc.

The network for Santiago de Chile has been modified twofold: First, for simplicity, the public transport network has been removed from the network since only busses are allowed to use them. Furthermore, missing streets and the (un)loading bays have been included into the network manually by creating new links and nodes and therefore existing ones needed to be adapted without changing the links´ characteristics such as the total length of a street, the number of lanes, the capacity and the speed.

Figure 4 presents the study area, the infrastructure with all nodes (turquoise) and links (dark grey) including the retail establishments (purple) and (un)loading bays (red circles), in the CBD of Santiago de Chile. The (un)loading bays itself have been included in a triangular shape consisting of 3 nodes (black) and 3 links (red). In this example, the (un)loading bay is *"shop1middle"*.

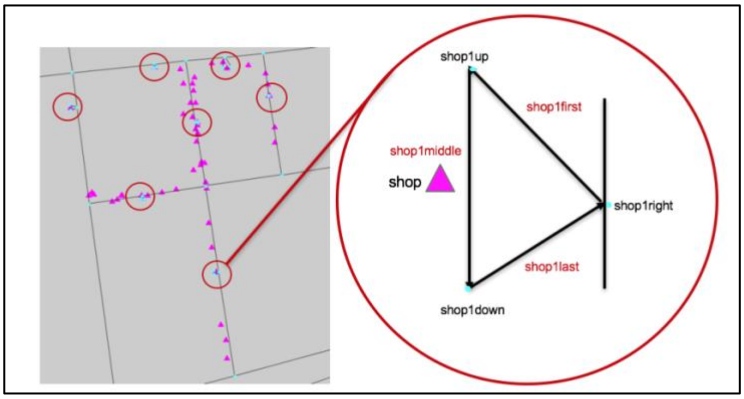

Fig. 4. Example for (un)loading bays

4.3. Vehicle data

Since it is assumed that the information on freight vehicles parking has been gathered at the same day and that for each of the 71 retail establishments only one delivery has been made, leads to the total number of 71 commercial vehicles delivering in the study area. Furthermore, all vehicles have been modelled as light commercial vehicles.

4.4. Delivery data

In order to create an origin-destination route, the coordinates of the shops were integrated into the network and the depot was located outside of the study area from which the carrier agents are starting. The service/parking duration is defined as the amount of time in which the vehicle remains parked at a given location while performing the delivery/pick up (Jaller, Holguín-Veras & Hodge 2013). Since the provided data set does not distinguish between delivery or pick up consistently, it is assumed that the purpose of service is a delivery.

Furthermore, the carriers have been separated into the four retail categories (*food service, clothing, grocery, others*), because otherwise all carriers would start from the depot at the earliest possible time, which is according to the data set at 10:30 am. Thus, a differentiated view of the retail categories allows a different start and ending time, which is gathered based on the collected delivery information. The destination is one of the available (un)loading bays that have been added into the network and are located in the same block as the shop served.

5. Construction of reference cases

To analyze the results of the simulation and to evaluate the performance of (un)loading in the study area, different parameter adjustments have been made. Thus, two reference cases have been generated, both of which are aiming at assessing the performance of (un)loading bays in the study area. These bays are assumed to accommodate either one or two vehicles at a time, depending on the scenario being considered, which are summarized in the following sections.

5.1. Reference case 1

To analyze the results of the simulation an initial scenario was constructed with the input parameters shown in Table 2.

Table 2. Input parameters for reference case 1.

Parameters	Value
capacity	1 unit
capacityDemand	1 unit
Service durations	Individual for each service; based on collected data
Time window	Individual per retail category; earliest start and latest end are based on provided data
Others	*1:40 pm – 4:40 pm*
Drug stores	*10:30 am – 8:00 pm*
Food service	*1:40 pm – 4:20 pm*
Clothing stores	*2:00 pm – 4:50 pm*

In order to build the initial reference case and to replicate the current status, the *capacity* and the *capacityDemand* are set on 1 unit excluding the case of each vehicle serving several shops and performing multi-tours. The service durations are individually set per carrier according to the provided data set. Additionally, the time window has also been set individually per retail category. Given the fact that the carriers disappear from the network at the location of the (un)loading bays for the time of their service duration (which is *'shop1middle'* in Figure 4) it can be stated that the (un)loading bays are not limited in size in terms of parking lots. The simulation results of the first reference case are summarized in Table 3.

Table 3. Simulation results of single-tour-carriers.

(Un)Loading bay	Occupancy rate (%)	Conflict of occupation (%)	Share of conflict with more than 2 vehicles (%)	Share of occupation with more than 2 vehicles (%)
Bay 1	1,06	0,00	0,00	0,00
Bay 2	9,48	59,96	26,70	16,01
Bay 3	11,94	80,34	95,98	77,11
Bay 4	13,67	47,28	52,46	24,81
Bay 5	0,88	0,00	0,00	0,00
Bay 6	2,57	60,80	5,79	3,52
Bay 7	1,69	44,73	86,87	38,86
Average occupancy rate over total capacity (%)	5,90			

The results are analyzed regarding the occupancy rate and the share of conflicts with more than two vehicles per (un)loading bay (see Table 3). According to Malik et al. (2017), the occupancy rate is defined as the ratio of time one single (un)loading bay is used to the time the (un)loading bay is supplied (Eq. 1), which is in all simulation scenarios from 10:30 am to 8 pm. As can be seen in Table 3, the (un)loading bays 3 and 4 present the highest occupancy rates and as a conclusion the highest demand for freight dedicated parking space. The highest vacancy rate is presented by (un)loading bays 1 and 5. This is due to the number of establishments and vehicles, in this case only one and two establishments (or vehicles), using the provided parking spaces for delivery purposes (see Table1). However, the approach used to run the simulation for reference case 1 does not consider the limitation of (un)loading bays in size, which explains the lower average occupancy rate over the total capacity than observed in practice.

$$Occupancy\ rate\ (\%) = \frac{(Un)Loading\ bay\ usage\ (h)}{(Un)Loading\ bay\ supply\ (h)} \times\ 100 \tag{1}$$

Furthermore, the conflict time of occupation has been determined, which is defined as the ratio of time each (un)loading bay is occupied by more than one vehicle to the time the (un)loading bay is used (Eq. 2). As can be seen in Table 3 the (un)loading bays 3, 6 and 2 present the highest conflict times of occupation. As it is the case for (un)loading bay 3, for example, approximately 81 % of the time delivery dedicated parking space is used by more than one commercial vehicle. Thus, a closer look at the number of vehicles occupying the freight dedicated parking spaces is needed.

$$conflict\ of\ occupation\ (\%) = \frac{(Un)Loading\ bay\ usage\ of\ more\ than\ 1\ vehicle\ (h)}{(Un)Loading\ bay\ usage\ (h)} \times\ 100 \tag{2}$$

Therefore, the time of occupation by more than two vehicles has been determined and in the following expressed as the share of conflict time and the share of occupation. In regards to the share of conflict, which is expressed as the ratio of time each (un)loading bay is occupied by more than two vehicles to the time the (un)loading bay is used by two vehicles (Eq. 3), the (un)loading bays 3, 7 and 4 present the highest demand for parking at the same time (see Table 3).

$$share\ of\ conflicts\ (\%) = \frac{(Un)Loading\ bay\ usage\ of\ more\ than\ 2\ vehicles\ (h)}{(Un)Loading\ bay\ usage\ of\ more\ than\ 1\ vehicle\ (h)} \times\ 100 \quad (3)$$

In regards to the share of occupation (Eq. 4), which is expressed as the ratio of time each (un)loading bay is occupied by more than two vehicles to the time the (un)loading bay is used, the same (un)loading bays 3, 7 and 4 present the highest demand for parking space as it is the case for the share of conflict.

$$share\ of\ occupation\ (\%) = \frac{(Un)Loading\ bay\ usage\ of\ more\ than\ 2\ vehicles\ (h)}{(Un)Loading\ bay\ usage\ (h)} \times\ 100 \quad (4)$$

To induce a shift of operations and spread the parking demand over the temporal parking capacity and thus reducing the parking congestion problem during the peak time, the parameters *capacity* and *capacityDemand* have been adjusted so that several shops per carrier are served. Assuming an average number of three shops per carrier, the capacity has been increased to 3 units and the demand is set on 1 unit, meaning that 3 shops are served per carrier. The shops served per carrier are either located on the same street, resulting in the vehicles using the same (un)loading bay for the time of the sum of each service duration per establishment, or the location of the shops varies, then, in this case, the carriers use different (un)loading bays for the time of each service duration per shop.

A comparison of the changes (in percentage points) in the simulation results of multi-tour- and single-tour-carriers are visualized in Figure 5 to facilitate the assessment.

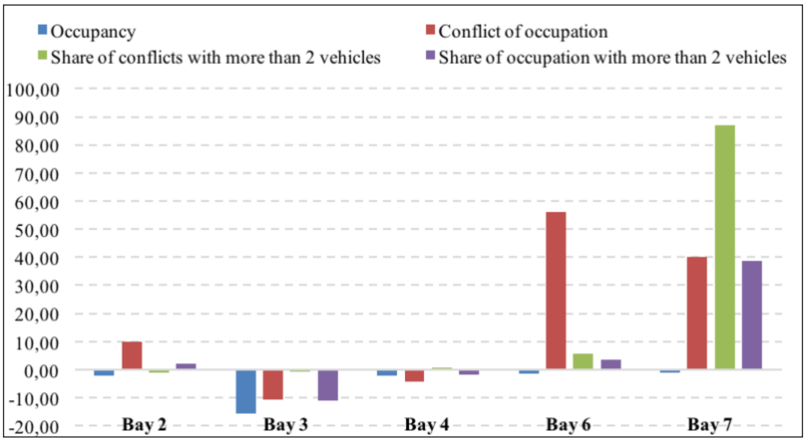

Fig. 5. Change of simulation results compared to single-tour-carriers (in percentage points)

As it can be seen in Figure 5, the (un)loading bays 6 and 7 show the highest decrease in the conflict of occupation, the share of conflicts and the share of occupation with more than two vehicles compared to single-tour-carriers. Especially the (un)loading bay 2 that represents the third-highest share of establishments benefits from the delivery vehicles performing multi-tours in terms of conflict of occupation, which has decreased for approximately 10 %. Thus, the simulation results regarding the conflict of occupation as well as the share of conflict and occupation with more than two vehicles expectations are confirmed as also shown in higher number of shops (5, 10, 15) served per delivery vehicle (see Appendix A). Regarding the occupation of (un)loading bays, (un)loading bay 3, which has the highest share of establishments shows the highest increase in its availability over the delivery time window (10:30 am-8 pm), expressed through a raise of 15,71 percentage points in the occupation rate (from 11,94 % to 27,65 %). Furthermore, the increase in the occupancy rates of all (un)loading bays can be explained by the higher number of establishments served per vehicle (3 shops per vehicle) compared to single-tour-carriers, which results in longer service durations and consequently, in a slight increase in the occupancy rates of all (un)loading bays (see Appendix A). However, the changes are in this case, except for (un)loading bay 3, less than 3 percentage points. Accordingly, it can be stated that performing multi-tours in the study area leads to a significant reduction of the performance parameters assessed and thus, improves the status quo as well as provides a solution to many problems encountered regarding conflict of occupation, the share of conflict and the share of occupation.

However, apart of assuming an average number of shops served per carrier, another important aspect to be considered is the number of deliveries per stop, which is not captured with the simulation algorithm used. Furthermore, in addition to the number of deliveries per stop, the simulation algorithm does not consider the several factors (e.g. average shipment size, higher number of carriers, urgency, concentration of receiver clients, parking availability, etc.) that influence the time required to perform the delivery/pick-up activities.

Jaller, Holguín-Veras & Hodge (2013) have determined a linear relation between the service duartion and occupancy rate in their work, because the amount of time the vehicle remains parked at a given location is directly related to parking turnover and ultimately the occupancy rate. Therefore, the initial scenario of single-tour-carriers has been performed by halving and doubling the service durations as provided in the data set in order to asses how a decrese or increase in service durations affects the occupancy rate. The simulation results for both cases are summarized in Appendix B and show that changes in service durations do affect the occupancy rate of the (un)loading bays in the study area, but the impact is not linear due to the simulation approach of (un)loading bays presented in this section that does not consider whether the targeted (un)loading bay is occupied. Thus, a two-fold increase in service durations decreases the average daily occupancy rate over the total capacity by approximately 93 %. In contrast, reducing the service durations by half decreases the average daily occupancy rate over the total capacity by approximately 57 %. These results indicate that the relationship is not linear, however, they indicate that improvements in operations help mitigate the parking issues (see Appendix B).

5.2. Reference case 2

In order to determine the waiting times as a complementary indicator for the efficiency of the system in addition to the occupancy rates, a new approach has been developed. As previously mentioned, the approach used in reference case 1 does not consider the limitation of (un)loading bays in size, since the delivery vehicles disappeare from the network while serving the shop(s) and thus, no differentiation in terms of parking lots can be made, which explains the lower average daily occupancy rate than observed in practice.

The main difference to the previously presented reference case 1 is that the (un)loading bay is defined as the link the carriers take before performing the delivery (which is *'shop1first'* in Figure 4). Therefore, the link characteristics of the (un)loading bays have been changed so that it can be used only by one single vehicle that can be interpreted as one parking lot per (un)loading bay. Consequently, the flow *capacity* of the link described through the number of vehicles using the link per hour and the *freespeed* of the same link, which is the maximum speed that vehicles are allowed to travel along the link described in meters per second, have been calculated for each (un)loading bay based on the collected data. Therefore, the proceeding is described as follows: Frist, the *service durations* have been converted into seconds, then the *capacity* has been calculated using the following formula (Eq. 5):

$$capacity\ (veh/h) = \frac{1}{Service\ duration\ (h/veh)} = \frac{3600}{Service\ duration\ (s/veh)} \tag{5}$$

To determine the *freespeed* the parameters *length* of the (un)loading bay and service durations have been placed in the following formula (Eq. 6):

$$v = \frac{d}{t} \tag{6}$$

$v = freespeed\ (m/s)$
$d = length\ (m)$
$t = service\ duration\ (s/veh)$

Working with this approach, in this case, the service durations are fixed for all carriers using one particular (un)loading bay and are expressed through the average parking duration of each (un)loading bay, which is, compared to reference case 1, the only difference in terms of the input parameters. For this reason, the service durations at each destination of delivery vehicles were set on 1 second because the service durations are already described by the characteristics of the previously link used. Further input parameters for running the simulation of reference case 2 are summarized in Table 4.

Table 4. Input parameters for reference case 2.

Parameters	**Value**
capacity	1 unit
capacityDemand	1 unit
Service durations	Fixed time; average parking duration per (un)loading bay based on collected data expressed through link characteristics
Time window	Individual per retail category; earliest start and latest end are based on provided data
Others	*1:40 pm – 4:40 pm*
Drug stores	*10:30 am – 8:00 pm*
Food service	*1:40 pm – 4:20 pm*
Clothing stores	*2:00 pm – 4:50 pm*

The simulation results can be analyzed twofold: The ***occupancy rates*** can be determined and the ***waiting times*** can be analyzed. Regarding the occupancy rate of the (un)loading bays, the simulation was performed twice: First, the link characteristics have been adjusted so that it can only be used by one vehicle, which can be interpreted as one parking lot per (un)loading bay. Another simulation has been performed with the link characteristics allowing two vehicles to use the same link at the same time (by doubling only the *capacity* of the same link), which can be interpreted as two parking lots per (un)loading bay. The simulation results that have been analyzed in regards to the occupancy rates are summarized in Table 5.

Table 5. Simulation results for reference case 2.

(Un)Loading bay	Occupancy rate of 1 parking lot (%)	Occupancy rate of 2 parking lots (%)	Occupancy rate change (%)
Bay 1	1,06	1,06	0,00
Bay 2	19,31	11,27	-41,64
Bay 3	166,01	86,33	-48,00
Bay 4	29,28	16,19	-44,71
Bay 5	0,88	0,88	0,00
Bay 6	4,22	2,82	-33,18
Bay 7	2,81	1,64	-41,64
Average occupancy rate over total capacity (%)	36,18	17,17	

The occupancy rates have been calculated according to Equation 1. Comparing the simulation results of the reference case 2 (see Table 5) with the simulation results of the reference case 1 (see Table 3), it can be stated that limiting the (un)loading bays to one or two parking lots leads to higher occupancy rates (except for (un)loading bays 1 and 5) of each (un)loading bay as well as average occupancy rate over the total capacity. This is due to the fact that the (un)loading bays in reference case 1 are not limited in size and thus no differentiation in terms of parking lots can be made. Furthermore, assuming one parking lot per (un)loading bay it can be seen that (un)loading bay 3 shows an occupancy rate of more than 100 %. Consequently, it can be concluded that implementing two parking lots for (un)loading bay 3 optimizes its current supply by almost 50 % and for (un)loading bay 4 the occupancy rate drops by 73 %. Thus, implementing two parking lots can be seen as a solution for handling delivery vehicles in the study area.

Moreover, the results have been further assessed regarding the change in service durations and its impact on the occupancy rates. As Jaller, Holguín-Veras & Hodge (2013) have shown in their work, there is a linear relation between the service duartion and occupancy rate, since the amount of time the vehicle remains parked at a given location is directly related to parking turnover. Therefore, the simulation has been performed by halving and doubling the service durations as provided in the data set in order to asses how a decrese or increase in service durations affects the occupancy rate. For a change in service durations, the link characteristics need to be adjusted as follows:

- For a decrease in service durations by half, the link characteristics *freespeed* and *capacity* need to be doubled.
- Conversely, for a an increase in service durations by two-fold, the link characteristics *freespeed* and *capacity* need to be halved.

The input parameters as well as the simulation results are summarized in Appendix C and show that changes in service durations affect the occupancy rate of the (un)loading bays in the study area linearly. Thus, a two-fold increase in service durations at each (un)loading bay increases the occupancy rate by 50 % of each (un)loading bay and would negatively affect the parking situation. In contrast, reducing the service durations by half decreases the occupancy rate by the same proportion and consequently, would greatly improve the system. These results indicate that the relationship between service durations and occupancy rate is linear and that improvements in operations help mitigate the parking issues.

Furthermore, the simulation results have been analyzed regarding the waiting times that are visualized in Figure 6 which shows the share of waiting time per (un)loading bay (in %). As it can be the (un)loading bays 2 (orange), 3 (grey) and 4 (yellow) represent the highest waiting times of more than 30 or 60 minutes. Unlike at (un)loading bays 2, 3 and 4, delivery vehicles at the (un)loading bays 1 and 5 do not wait for (un)loading activities. Furthermore, at (un)loading bay 3 the majority of delivery vehicles (92 %) waits for more than one hour to serve the shop. However, the simulation results for analyzing the waiting times have been presented here for the case that each (un)loading bay provides one parking lot for delivery activities, although providing two parking lots for (un)loading bay 3 and 4 have been identified as a solution for handling delivery vehicles since the occupancy rates reduce significantly (see Table 5). The analysis of the simulation results in regards to the waiting times for the case that each (un)loading bay provides two parking lots for delivery activities can be seen in Appendix D. In sum, the results for providing two parking lots per (un)loading bay show a significant reduction in waiting times and a lower number of delivery vehicles waiting for more than 30 minutes.

Moreover, the simulation results have been analyzed regarding the resultant waiting times due to changes in service durations for the case that each (un)loading bay provides one parking lot for delivery activities (see Appendix E and F). Overall, it can be stated that a decrease in service durations by half leads to a lower number of vehicles waiting for more than 30 minutes. In contrast, a two-fold increase in service durations leads to a significant increase in waiting times of more than one hour.

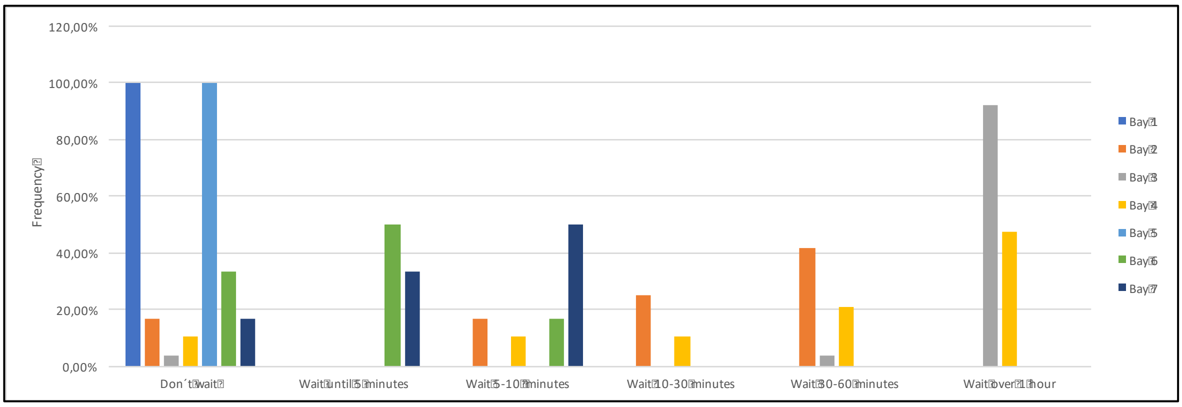

Figure 6. Share of waiting time per (un)loading bay (in %)

However, the determined waiting times of the carriers can be interpreted as the time spent for cruising/searching for alternative parking spaces because the tour for each carrier is planned before their trip and thus, no changes can be made in the tour planning during the trip, when the targeted (un)loading is already occupied. In addition, Furthermore, all carriers started from the depot at the earliest possible time, which is according to the data set at 10:30 am and thus, they may not be as high as observed in practice.

In order to comprehensively evaluate commercial vehicle parking strategies, additional research is needed. As the tour planning algorithm does not include other infrastructure users, the impact of illegal occupation of (un)loading bays by other commercial vehicle(s) or other transport users in the network cannot be investigated. In addition, further improvement can be achieved through the adjustment of the tour planning algorithm so that the starting time for delivery operations of the carriers can be changed. Additional aspects to be considered in the existing model are the number of deliveries per stop and the cruising for parking to estimate the broad impacts of freight deliveries in the inner-city area of Santiago de Chile and elsewhere. Therefore, prior knowledge of parking availability needs to be integrated in the parking choice model.

6. Conclusions

The main purpose of the present article was to assess the parking conflicts and a potential improvement that an optimized (un)loading bay system in the CBD area in Santiago de Chile can achieve when compared to the existing one. The findings presented and discussed in this work have considerable planning and policy implications since they show identified parking issues in Santiago de Chile go hand in hand with the weak institutional control mechanisms. Furthermore, to conduct the assessment of the current demand and supply situation of (un)loading bays in Santiago´s CBD two different approaches representing two different reference cases have been developed through which different key indicators (occupancy rate, conflict time of occupation, waiting times) can be determined.

To investigate the parking demand based on the provided data, three necessary inputs were given: number of trips attracted by each establishment type, the number of establishments and the duration of parking, whereby the supply is equal to the amount of available (un)loading bays in the study area. Overall, the simulation results indicate that there is a significant deficit of freight dedicated parking spaces on certain streets with commercially intensive activities in the investigated area and, moreover, that there is an urgent need for action.

Apart of analyzing the occupancy rates, the conflict time of occupation and the waiting times of the current freight parking situation, the relationship between service duration and occupancy rate as well as the resultant waiting times due to changes in service durations have been assessed for all reference cases. When analyzing to what extent the service durations affect the occupancy rates in reference case 1, which does not consider the limitation of (un)loading bays in size in terms of parking lots, no linear relationship is found. However, when increasing the number of shops served per carrier, significant improvements in conflict time of occupation have been shown.

In contrast, the simulation results in reference case 2, which provides one or two parking lots at each (un)loading bay, show that changes in service durations affect the occupancy rate linearly. Furthermore, a decrease in service durations by half leads to a lower number of vehicles waiting for more than 30 minutes. A two-fold increase in service durations leads to a significant increase in waiting times of more than one hour.

Furthermore, it can be concluded that the determined waiting times of the carriers can be interpreted as the time spent for cruising/searching for alternative parking spaces because the tour for each carrier is planned before their trip and thus, no changes can be made in the tour planning during the trip, when the targeted (un)loading is already occupied.

As a conclusion, the simulation results indicate that improvements in operations (service durations, number of deliveries per vehicle), help to alleviate the parking problem in the investigated area. However, these parameters depend on other operational constraints (e.g. shipment size, parking availability, concentration of receivers, etc.) and thus, it is not likely that implementing a parking management strategy (e.g. parking pricing or strict enforcement policy) in addition to the existing time restriction in Santiago de Chile has further impact on the parking durations as the problem is not caused by the misbehavior of delivery vehicle drivers but rather of the operational setting of freight deliveries. However, parking pricing can be an effective tool to encourage off-hour deliveries. In addition, optimizing the (un)loading bays in size leads to overall improvements across the assessed key indicators, especially at (un)loading bays for which the demand is approximately two times higher than the capacity.

Although the present article provides a general approach to assess freight dedicated parking facilities, there are also some limitations. Further improvement can be achieved through the adjustment of the tour planning algorithm so that the starting time for delivery operations of the carriers can be changed. Additional aspects to be considered in the existing model are the number of deliveries per stop and the cruising for parking to estimate the broad impacts of freight deliveries in the inner-city area of Santiago de Chile and elsewhere.

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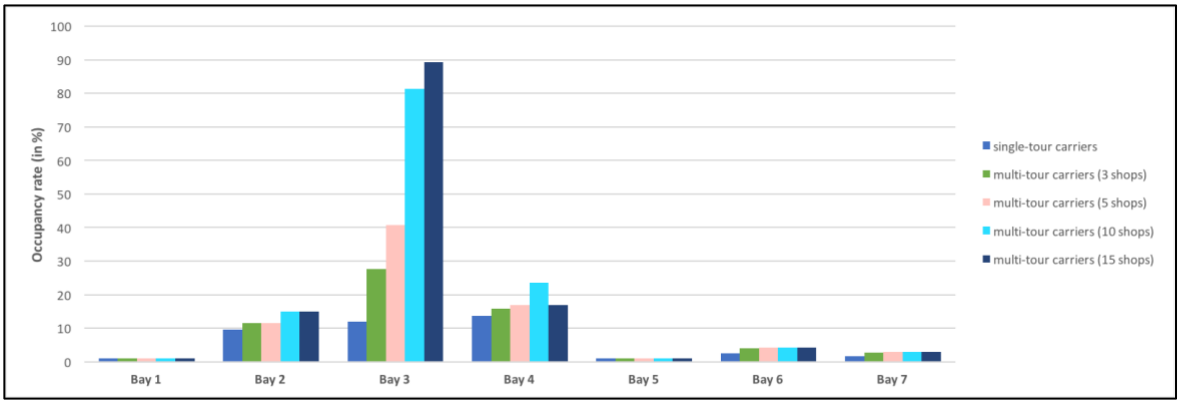
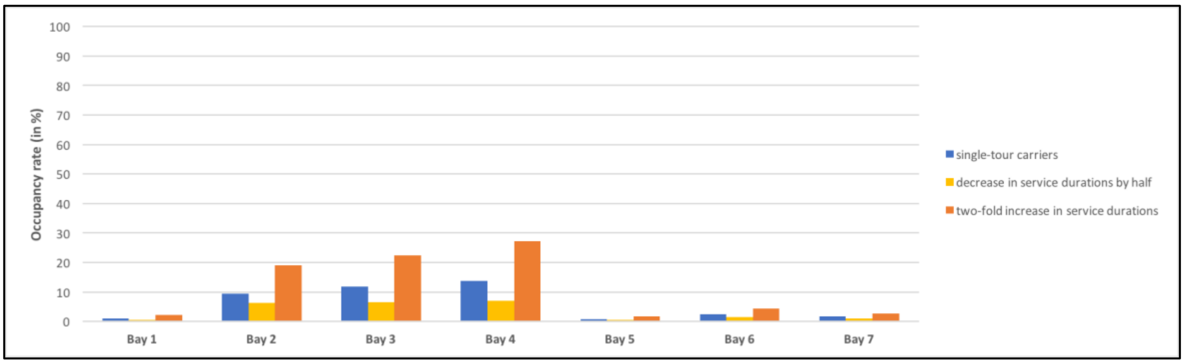
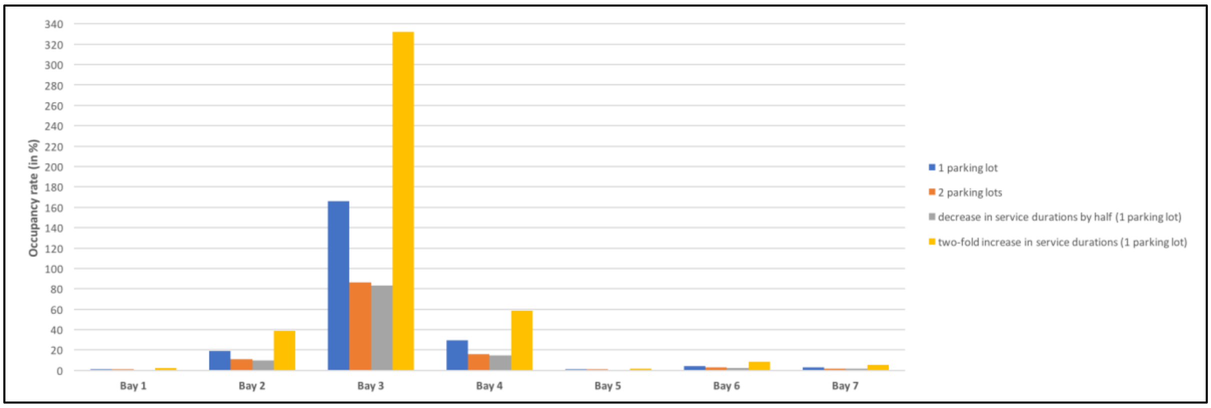
Appendix A. Comparison of occupancy rates for single-tour and multi-tour carriers per (un)loading bay



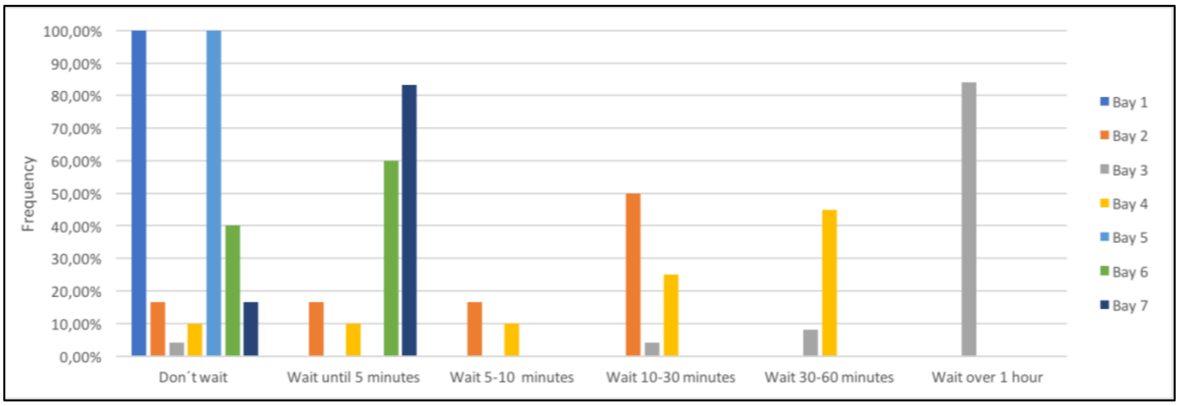
Appendix B. Comparison of occupancy rates for different service durations in reference case 1



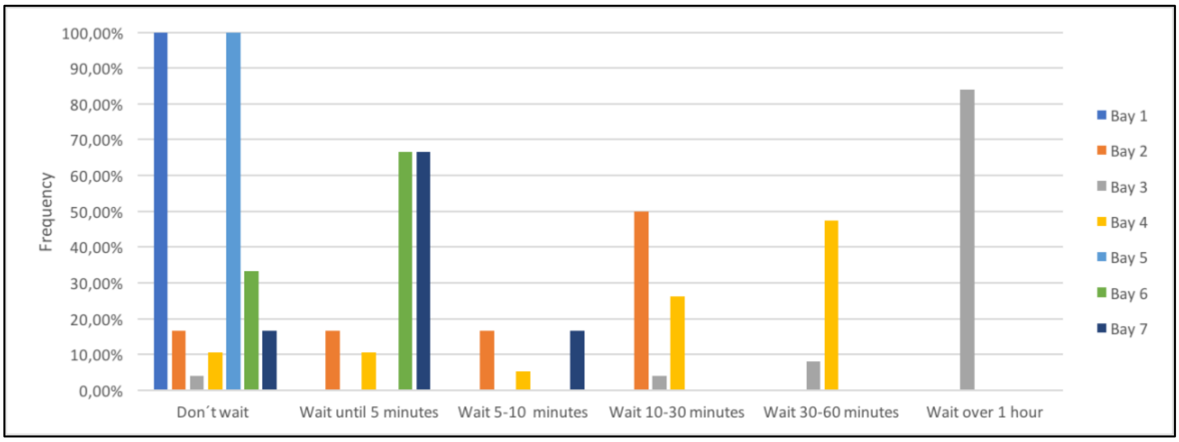
Appendix C. Comparison of occupancy rates for different service durations in reference case 2



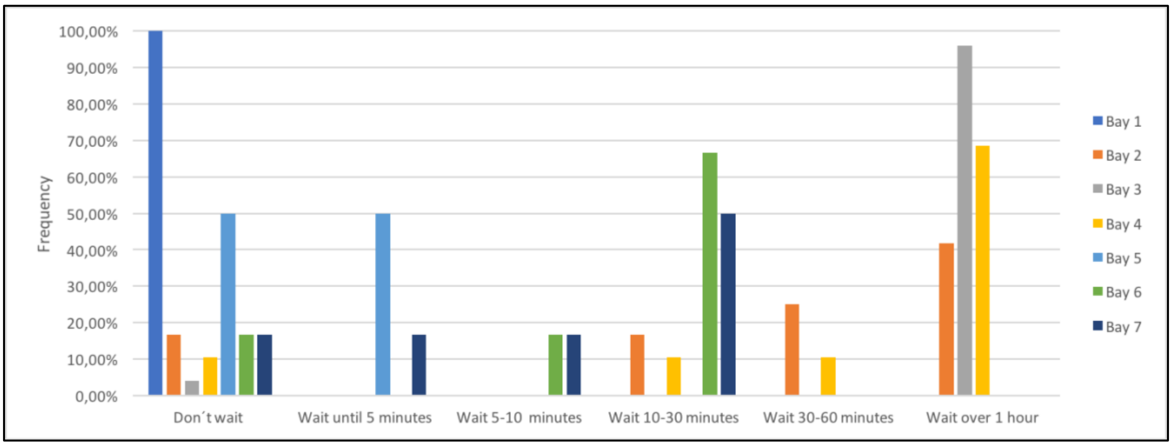
Appendix D. Share of waiting time per (un)loading bay (in %) in reference case 2 for (un)loading bays with two parking lots



Appendix E. Resultant waiting times due to a decrease in service durations by half in reference case 2



Appendix F. Resultant waiting times due to a two-fold increase in service durations by half in reference case 2



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