Efficient loading and unloading operations via a booking system

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Abstract

Urban distribution of parcels and goods usually requires vehicles to temporarily stop at roadside to allow for the driver to perform the last leg of the delivery by foot. The stops take place in designated areas, called loading/unloading (L/U) areas, composed of one or more parking spots. In this paper the introduction of a booking system for the management of the L/U areas in a city center is studied as a way to eliminate, or at least substantially reduce, double parking. A booking management system and the related routing problem are presented. In this system, distributors book in sequence according to their preferences and routing constraints, but subject to the bookings that have already been placed. The solution provided by the booking system is discussed and compared with the current use of the L/U areas, where the distributors do not consider the availability of a parking spot and resort to double parking if none is available.

Keywords: loading/unloading areas, urban logistics, booking management, double parking, routing.

1 Introduction

The rapid increase of demand of goods and services in the city center and the comparatively static nature of the road infrastructure, among other aspects, make distribution in the urban areas a very relevant topic. This increase of demand in urban areas is the result of various factors, such as the increasing rate of urbanized population expected to reach 80% worldwide by 2050 (see Bettencourt and West [2010]), as well as social and economic growth. These phenomena, together with technological advancement and the wide adoption of e-commerce, have also caused the need for fast and readily available distribution systems. The management of the road network is therefore assuming a more and more relevant role in the quality of the distribution system of an urban area and in the quality of life of its citizens. These and many other aspects of the challenges and opportunities of city logistics are discussed in Savelsbergh and Van Woensel [2016].

In this context, the management of loading and unloading zones reserved by the municipality to commercial vehicles is considered. City distribution usually requires vehicles to temporarily stop at roadside to allow for the driver to perform the last leg of the delivery by foot. The stops take place in designated areas, called loading/unloading (L/U) areas, each with a specific number of available parking spots. Distributors often face bottlenecks at L/U areas due to various factors, such as peaks in the delivery requests either in time, in space, or both, e.g., all shops in the fashion district requiring the clothes to be delivered in the morning, or systemic problems in the allocation of L/U areas, e.g., scarcity or poor placement of the spots. The response of drivers to the unavailability of L/U spots is often double parking. The high demand for L/U areas and the scarcity of space available in city centers make the management of such areas a crucial factor in the city distribution for all the stakeholders involved. The municipality wants to reduce double parking and its negative impact on traffic, the distributors want to easily access L/U areas to minimize the cost of delivery and do not want the infrastructure to worsen their service quality. Not finding available parking spots, experiencing inconveniences such as vehicles that have double parked or fines for double parking are the major undesired phenomena met by distributors. The L/U areas are identified by the municipality but typically little to no management is performed after the locations have been established. In some cases a time limit on each stop is imposed, e.g., by means of a parking disc, to reduce the use of the areas. Enforcement of such limits is normally allocated to the traffic police.

The management of L/U areas can be seen as the tactical level of a decision-making framework that, at the strategic levels, requires the location and sizing of the areas to be made available and that, at the operational level deals, with the daily decisions made by the distributors in preparing their vehicles and dealing with the inevitable (mostly small) disturbances of traffic and not full readiness to receive the loads by some of their clients. In this paper, a proof of concept for a booking management system is presented and its performance is assessed to test whether has the potential to become a valid approach to deal with double parking and to what extent it affects the efficiency of the operations of the distributors. In this approach, distributors book in sequence according to their preferences and routing constraints, but subject to the bookings that have already been placed. As we address the tactical level of this problem, the issues arising when planning the routing of the vehicles will be simulated by means of a routing problem. The data on which the performance of the proposed system, and the related simulation of the behavior of the vehicles, has been tested is based on the real case of the Baixa neighborhood of Lisbon, Portugal, for which a 2012 unpublished consultancy study of logistical practices in the area was made available to the authors and a small survey was conducted among some of the distributors of the area.

1.1 The contributions of this paper

One of the ways to deal with double parking arising from the misuse of L/U areas is to regulate the use of the parking spots through a booking system, controlled by the municipality with compulsory booking made by the distributors. With a booking system the use of L/U areas would shift from being similar to the one of an open access car park, where vehicles occupy a spot as soon as it becomes available and double park or cruise for parking if all the spots in the desired area are taken, to one where each distributor has to place a booking to the L/U areas booking system to access a spot, similar to the practice of booking a table for a meal or a hotel room for an overnight stay. A booking for an L/U area would consist of the starting time and the desired length of the stop (a maximum allowed length of stay would be defined by the municipality). The booking would be made possible by a front-end interface, e.g., a website. Several systems could be conceived to control the parking in the L/U areas, such as GPS or RFID-based systems, possibly also including detection of unregistered vehicles. To the best of our knowledge, the only paper that proposes a centralized approach for the management of the L/U areas is Roca-Riu et al. [2015]. The authors define the parking slot assignment problem on L/U areas with given capacity as the problem of finding a feasible assignment of the requests of the distributors to the parking spaces of the area, such that the time window for the beginning of each request is satisfied and that the capacity of the area is not violated. It is, however, assumed that the distributors will be able to re-optimize their routes so as to arrive on time to the assigned parking space.

In this paper, the choice of routes and delivery times at each of the L/U spots is left with the distributors, subject to the respect of the slot allocations made by other distributors who booked earlier. To represent the behavior of the vehicles when the L/U areas infrastructure saturates and double parking is unavoidable, violations of the available booking times are allowed but heavily penalized.

The scope of this paper is to present and analyze a booking system of the parking spots available in the L/U areas, aimed at eliminating, or substantially reducing, the double parking phenomenon. **As, after a distributor has assigned customers to vehicles, the routing of each vehicle is independent of the others**, without loss of generality, we assume that each distributor owns one vehicle and we use the terms distributor and vehicle interchangeably. A booking system where parking spots are booked by each distributor over time, in sequence, is proposed and analyzed. Each time a distributor wants to place a booking, it queries the booking system which replies with the free time windows for each L/U area, that is, the time intervals in which at least one parking spot of the L/U area is not booked. These bookings **are** the outcome of a routing solution designed by the distributor to minimize his costs possibly constrained by customer-defined time windows. The distributor can then place a booking for a particular L/U area only if compatible with the time intervals in which the requested area is currently available. Henceforth, we call these intervals time windows. As the booking system is only in charge of providing the current state of the booking of the area and checking if the new booking violates the capacity constraints of the areas, bookings can be placed at any time and an immediate confirmation is given to the distributor. To represent the reality of the distribution in a city center, where the L/U area infrastructure may saturate, we take into account that the distributors might violate the time windows, e.g., as result of an early or late arrival, or if the time window which the distributor wishes is not wide enough for his desired length of stay. This violation is heavily penalized in the model we present.

For the purpose of performance assessment, different operational settings are considered. In the first, each distributor fixes the starting time of the delivery route in the city center and tries to find the shortest route serving all his clients subject to available L/U slots (priority to starting time). In the second, distributors are flexible with respect to the starting time of their routes, allowing the model to find solutions with the shortest delivery routes (priority to route duration). The first setting has fixed (distributor-defined) starting times of the routes, whereas in the second the starting times are flexible. A third approach is also considered, where distributors declare a preferred starting time but also express their flexibility in terms of how much the starting time can be postponed. The routing problem faced by a vehicle in each of the operational settings is modeled as a Traveling Salesman Problem with Multiple Soft Time Windows (TSP-MSTW), a new variant of the classical TSP.

The proposed booking system, under the different operational settings, is simulated and compared with the current practice of use of the L/U areas, where each distributor performs its deliveries disregarding the capacity of the areas and resorting to double parking if all the spots are occupied by other vehicles. Test instances are generated based on the layout of the city of Lisbon and on data coming from a 2012 study and a survey submitted in 2018 to local carriers. The computational experiments show that, as a consequence of the preference of distributors for relatively early deliveries, in the setting with fixed starting times the routes of the distributors become substantially longer with respect to the current practice, especially for the late bookers, while under the setting with flexible starting times it is possible to obtain routes that are as short as in the current practice and do not suffer from the double parking problem. Furthermore, the results highlight the maximum number of vehicles that can perform operations in the city before the system saturates and vehicles have to resort to double parking as no booking time is available in the areas.

The paper is organized as follows. **A review of the relevant literature is presented in Section 2. The methodology is discussed in Section 3. Results are presented in Section 4. Conclusions are drawn in Section 5.**

2 Related literature

In this section general references to the literature on the planning and management of the L/U areas are presented. Papers dealing with both the strategic and tactical levels are covered.

Various papers deal with the problem of sizing and locating L/U areas in an urban environment. Muñuzuri et al. [2017] presents different alternative approaches to estimate the demand of loading zones. The number of loading areas is established based on the approach chosen among those proposed and the desired level of service. Then, the location of the areas is found by solving a *MinDist* location-allocation problem. The proposed methodology is tested on four streets in Seville, Spain. Pinto et al. [2019] proposes to identify the number and location of L/U areas by means of a "covering principle" based on the longest distance a delivery operator is willing to walk, and to define the number of spots in each area based on demand. The method is tested on instances generated for the city of Bergamo, Italy. The sizing and locating of L/U areas is also studied in Dezi et al. [2010]. The authors also discuss the issue of the spatial configuration of the infrastructure, presenting the case of Bologna, Italy. The impact of parking availability on commercial vehicle costs and operations is studied in Figliozzi and Tipagornwong [2017]. Among other aspects, the authors investigate how the insufficient availability of on-street parking and L/U areas during certain periods of the day in dense and congested urban areas affects the behavior of the distributors. The authors conclude that double parking is unlikely to disappear from urban areas unless more dedicated L/U areas are made available at peak times and that increasing parking fines and enforcement of the regulations can discourage double parking but will not eradicate the problem for a sufficiently high demand/supply ratio. In turn, however, the shortage of available parking spots for commercial vehicles is caused not only by an undersized infrastructure but frequently also by the misuse of the reserved spots by private vehicles, as reported by Aiura and Taniguchi [2005] and Alho et al. [2018]. Aiura and Taniguchi [2005] studies the facility location problem of the planning of on-street L/U spaces by minimizing the total cost function, including fixed cost, operational cost, parking fee and waiting cost while taking into consideration the behavior of pickup-delivery vehicles as well as passenger cars. The authors conclude that the management of such infrastructure needs to be reviewed both at the planning and evaluation level. Alho et al. [2018] studies the reduction of the double parking of freight vehicles by changing the spatial configuration of L/U areas and the non-freight vehicles parking rule compliance level. Among the findings of the paper, the authors report the disproportionate effects of the externalities caused by double parking, which can be the cause of delays and decrease the average speed on the network. Roca-Riu et al. [2017] studies the dynamic allocation of driving lanes to L/U operations to maximize delivery opportunities while reducing traffic disruption. A simulation study is used to evaluate the model and estimate its benefits compared to real situations where commercial vehicles resort to double parking. The authors devise the conditions under which the temporal allocation of shoulder lanes as L/U areas reduces the vehicles delay compared to the case where commercial vehicles resort to double parking.

A parking choice modeling simulation is presented in Nourinejad et al. [2014] for the study of truck parking policies, capturing various dimensions of the parking activity such as walking distance, congestion impact and parking search times. Two scenarios based on the Toronto area are presented to validate the model.

The issue of the pricing of L/U areas has also been considered in the literature. An auction-based approach for the assignment of time slots of a single area with multiple parking spots is considered in Yang et al. [2019] to optimize the performance of a management system while providing a fair assignment of the slots. The time preferences and service duration of the booking requests are considered in finding the best possible assignment.

In Letnik et al. [2018] a sizing problem taking into account the management of the L/U areas is studied. A two phase algorithm is proposed for the problem. In the first phase, the location of the L/U areas is optimized based on the location of the recipients of the goods. In the second phase, the algorithm optimizes the deliveries from outside the city to the L/U areas. L/U areas are assigned to vehicles and when none is available vehicles are put in a queue. The benefits of a booking system for the L/U areas are evaluated in McLeod and Cherrett [2011] for the case of Winchester High Street. Each vehicle is assumed to arrive from one of eight possible entry points and stop an one L/U area, with the possibility of relocation to another area if the one requested is not available. A control system dealing with operational issues such as vehicles arriving early or late is also presented.

It is worth reporting that efforts to introduce a L/U areas management system have been introduced in various cities around the world. For instance, in the DUM program in Barcelona[1], distributors are requested to check-in and check-out of each L/U operation with an SMS or an app in a smartphone, but, at the moment, no reservation can be placed.

3 Methods

In this section the methodology adopted for the problem is presented. First, the proposed booking approach is introduced in Section 3.1, then in Section 3.2 the routing problem arising in the approach is presented.

3.1 A sequential booking approach

The usage and management of L/U areas are typically regulated by simple policies, such as hours of active status and a maximum dwelling time, enforced by the police with on-site controls. More advanced management systems are prevented by the absence of information on the usage of the areas by the distributors. In turn, the approach of the distributors

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[1] `https://www.areaverda.cat/en/information/users/urban-goods-distribution`

is to disregard the capacity and the number of free spots of the areas –as they have no information on availability– and to double park if necessary, leading to an inefficient use of the areas and an increased cost for the stakeholders and for all the the other users of the road space in the areas. An example of the occupancy level of an area over time, when no booking management is in place, is shown in Figure 1, considering an area with a capacity of two vehicles where five have to stop in the represented time interval. The arrival time of vehicle i is denoted as "A_i" and the departure as "D_i". In this example the fourth vehicle in the sequence arrives in an area that is fully occupied, and double parks. The situation is worsened by the arrival of the fifth vehicle in the sequence.

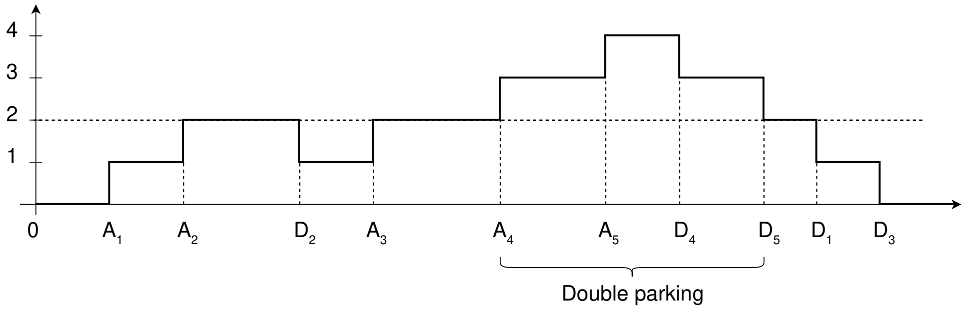


Figure 1: The occupancy level of a L/U area.

A booking system is proposed where all vehicles having to deliver goods to customers (or collect from them) in the city center can place bookings for the L/U areas. In this booking system, each of the distributors that have to deliver goods in the city center independently places bookings for the requested L/U areas, whose availability is dependent on the bookings already placed by other distributors. We call this the *sequential booking approach*. More in detail, for each distributor this system works as follows. When the set of deliveries to be performed is known, that is, the set of L/U areas to be visited and the desired length of the stay in each selected area, the distributor can obtain from the booking system the set of available time windows for the requested L/U areas (e.g., by logging-in in the booking website). Once all this information is known, the distributor obtains the tour to be performed by the vehicle by solving a routing problem where each visit to an L/U area must happen within one of the time windows in which the area has not been fully booked by previous bookings. If no such time window exists or those available are not wide enough to fit the length of the stay required at the area, the vehicle resorts to double parking for the time exceeding the available time window. Once the distributor has planned its distribution it books the stops it needs. The bookings happen in sequence, that is, the booking of the k^{th} distributor has to take into account all the bookings placed by the $k-1$ distributors that have already booked and, thus, define time windows of (un)availability of the areas.

The sequential booking system has the benefit of being a relatively simple method to introduce booking as a way to manage L/U areas and contribute to reduce double parking.

It would be easy to implement by the municipality, that only has to keep track of the bookings that are made, and would require little effort from the distributors and therefore has a high chance of being well-received. Enforcement would also be relatively easy, as all vehicles would have to be pre-registered and the presence of any vehicle in a L/U area slot would be automatically checked against its valid registration and booking time for the area.

3.2 Routing problems in the sequential booking system

As mentioned in the introduction, different operational settings are considered. In the first, each distributor fixes the starting time of its route, whereas in the second the starting time of the route is a decision variable that is left open. In the third approach, the earliest starting time is declared by the distributor that also defines the maximum delay to that starting time. For each of the settings, an optimization model is required for the routing problem. In the fixed starting times setting the route, that is the sequence of customers to be visited, has to be found, whereas in the second and third the route and its starting time have to be obtained. In all cases, the route has to take into account the time windows of availability of the requested L/U areas, determined by the bookings of the previous distributors. In this section, a formulation for the Traveling Salesman Problem with Multiple Soft Time Windows (TSP-MSTW), a new variant of the Traveling Salesman Problem, is first introduced as common foundation on which the model to be solved in each approach is based. Then, the variant of the model used in each approach is presented. For the sake of simplicity in the remainder of this section we focus on a single vehicle and ignore the vehicle index. **The problem is introduced to represent the actual routing problem that each distributor solves to plan its delivery.** The urban environment is modeled through a directed graph $G = (V, A)$, where $V = \{0, 1, \ldots, |U|, |U| + 1\}$ is the set of vertices and A the set of arcs connecting pairs of vertices. The vertices $U = \{1, \ldots, |U|\}$ represent the L/U areas in which the vehicle has to stop. Vertex 0 and $|U| + 1$ indicate the same vertex representing the starting and ending point of the route. A traveling time is associated with each arc $(i, j) \in A$ and denoted as t_{ij}. The required length of the stop at vertex i is denoted as $s_i > 0$. Each area $u \in U$ is characterized by a set of time windows W_u in which it has not been fully booked by previous bookings. We denote as H_u the index set of W_u, i.e., $H_u := \{h \in \mathbb{N} | W_{uh} \in W_u\}$. Time windows in W_u are denoted as W_{uh} with the lower and upper bound of the h^{th} time window of L/U area u denoted as W^a_{uh} and W^b_{uh}, respectively, that is, the area u is not fully booked from time W^a_{uh} to W^b_{uh}, included. Time windows may be violated but are **penalized** with a penalty factor M for each time unit of violation, both in the arrival and in the departure time.

Finally, all bookings must happen within the window of operation of the area, defined by the interval $[0, D]$, where D represents the latest time of delivery operations in the L/U areas. The TSP-MSTW is the problem of finding the shortest route starting and ending at vertex 0 such that the vehicle stops in one of the available time windows for each of the L/U areas.

The formulation of the TSP-MSTW relies on the following variables:

- $x_{ij} = \begin{cases} 1 \text{ if the route travels through edge } (i, j) \in A, \\ 0 \text{ otherwise,} \end{cases}$
- $T_i \geq 0$, the arrival time of the vehicle to vertex i,
- $y_{uh} = \begin{cases} 1 \text{ if the vehicle stops at area } u \text{ in the time window } W_{uh},\ h \in H_u, \\ 0 \text{ otherwise,} \end{cases}$
- $\gamma_{uh} \geq 0$, amount of earliness of the arrival w.r.t. W^a_{uh},
- $\lambda_{uh} \geq 0$, amount of lateness of the departure w.r.t. W^b_{uh}.

Time is assumed to be discrete, that is, $t_{ij}, s_i, T_i, \in \mathbb{N}$, for all $i, j \in V \cup |U + 1|$, and $W^a_{uh}, W^b_{uh} \in \mathbb{N}$, for all $u \in U, h \in H_u$. The resulting model is the following:

$$\min T_{|U|+1} - T_0 + M \sum_{u \in U} \sum_{h \in H_u} (\gamma_{uh} + \lambda_{uh}) \tag{1}$$

s.t.

$$\sum_{u \in U} x_{0u} = 1 \tag{2}$$

$$\sum_{u \in U} x_{u(|U|+1)} = 1 \tag{3}$$

$$\sum_{i \in \{0\} \cup U} x_{iu} = \sum_{i \in U \cup \{|U|+1\}} x_{ui} = 1 \qquad u \in U, \tag{4}$$

$$T_i + s_i + t_{ij} - T_j \leq M(1 - x_{ij}) \qquad i \in \{0\} \cup U, j \in U \cup \{|U| + 1\}, \tag{5}$$

$$T_u \geq W^a_{uh} y_{uh} - \gamma_{uh} \qquad u \in U, h \in H_u, \tag{6}$$

$$T_u + s_u \leq W^b_{uh} + M(1 - y_{uh}) + \lambda_{uh} \qquad u \in U, h \in H_u, \tag{7}$$

$$\sum_{h \in H_u} y_{uh} = 1 \qquad u \in U, \tag{8}$$

$$x_{ij} \in \{0, 1\} \qquad i \in \{0\} \cup U, j \in U \cup \{|U| + 1\}, \tag{9}$$

$$T_i \in [0, D] \qquad i \in \{0, |U| + 1\} \cup U, \tag{10}$$

$$y_{uh} \in \{0, 1\} \qquad u \in U, h \in H_u, \tag{11}$$

$$\gamma_{uh} \geq 0 \qquad u \in U, h \in H_u, \tag{12}$$

$$\lambda_{uh} \geq 0 \qquad u \in U, h \in H_u. \tag{13}$$

The objective function (1) minimizes the tour length of the vehicle and the total penalty for violation of booked periods (double parking by the distributor or imposed on others).

Constraints (2) and (3) impose that the route starts at the depot and ends at the return depot. Constraints (4) are flow conservation constraints. Constraints (5) regulate the arrival time of the vehicle at each vertex. Constraints (6) and (7) impose the lower and upper bound of each time window and model the earliness and lateness of arrival. Constraints (8) impose that only one time window per L/U area is used. Constraints (9)-(13) are domain constraints.

Routing problems with multiple time windows have been first introduced in de Jong et al. [1996]. The authors present a mathematical formulation for the vehicle routing problem (VRP) with multiple time windows (VRPMTW) and describe an Insertion-and-Savings method for the solution of the problem. Despite the high relevance in the reality of distribution planning, the problem has received limited interest after its introduction in the literature. A hybrid variable neighborhood tabu search is presented in Belhaiza et al. [2014] for the VRPMTW. The TSPMTW is discussed in Pesant et al. [1999], that adapts a constraint programming algorithm presented for the TSPTW (see Pesant et al. [1998]) to handle multiple time windows. The variant of the VRP with multiple interdependent time windows is studied in Doerner et al. [2008], where the characteristics of the perishable product, i.e., blood samples, introduce interdependencies between all pickups in a tour. Furthermore, the production of samples is considered to be not necessarily constant. Related problems are also presented in the literature discussing the team orienteering problem (see Lin and Vincent [2015] for a recent contribution).

Modeling a fixed starting time

Let q be the fixed starting time of the vehicle whose optimal route must be found. The routing problem in the case of fixed starting time of the route can be modeled with the following additions to formulation (1)-(13):

$$t_{0i} = 0 \qquad i \in U \cup \{|U|+1\}, \tag{14}$$

$$t_{i(|U|+1)} = 0 \qquad i \in \{0\} \cup U, \tag{15}$$

$$s_0 = 0, \tag{16}$$

$$T_0 = q, \tag{17}$$

where constraints (14) and (15) indicate that the distance of the source and sink depots from the L/U areas is set to zero. This is justified by the focus of this paper which is the portion of routing of the vehicles that affects the usage of the L/U areas, meaning the portion of routing that takes place within the city center. Constraints (16) and (17) allow the vehicle to park at the first area to be visited at time q, the starting time of the L/U operations selected by the distributor. Note that constraint (17) is such that the objective function (1) becomes the minimization of the time at which the vehicle reaches the sink depot, i.e., the ending time of the tour of the vehicle, minus the constant q. This is also equivalent to minimizing the route duration while imposing the starting time q on the route. We call this variant of the routing problem "TSP-MSTW-fixed" and the sequential approach where a TSP-MSTW-fixed is solved for each vehicle "SEQ-fixed".

Modeling a flexible starting time

As it should be expected, given the preference of most distributors for early deliveries in the city center, and as the computational experiments will show, independent choices of starting times by the distributors easily lead to concentrations of demand and imposed waiting periods before the next desired slot is available. For this reason, a different situation is studied where the distributors do not have a predefined time at which they arrive in the city center, leaving to the optimization problem the task of identifying the time at which the first area in the tour is visited. This is achieved by adding to formulation (1) - (13) constraints (14) - (16). The objective function (1) is equivalent to the minimization of the route duration. We call this variant of the routing problem "TSP-MSTW-flexible" and the sequential approach where a TSP-MSTW-flexible is solved for each vehicle "SEQ-flexible". In practice this could be seen as tool for the municipality (via the booking system) to specify a time interval for each vehicle to enter the city center and serve its customers, in an effort to reduce the concentration of parking requests.

Modeling approaches "in between" the SEQ-fixed and SEQ-flexible

The SEQ-fixed and the SEQ-flexible approaches represent two extreme cases of the modeling of the logistics of delivering in a city center taking L/U areas availability into consideration. In between solutions can be modeled by adding to formulation (1) - (13) and (14) - (16) the following constraints:

$$T_0 \geq q, \tag{18}$$

$$T_0 \leq q + f, \tag{19}$$

where q is the desired starting time specified by the distributor and f is a flexibility parameter. Constraints (18) and (19) model the fact that the first visit of the vehicle must happen after time q, respecting the requirement specified by the distributors, and before time $q + f$, expressing the flexibility that the distributor might have in such starting time. We call this variant of the routing problem "TSP-MSTW-semiflex" and "SEQ-semiflex" the sequential approach where a TSP-MSTW-semiflex is solved for each distributor. In both cases the addendum "-f" is specified when addressing the results for a specific value for f. Note that the SEQ-semiflex-0 is equivalent to the SEQ-fixed.

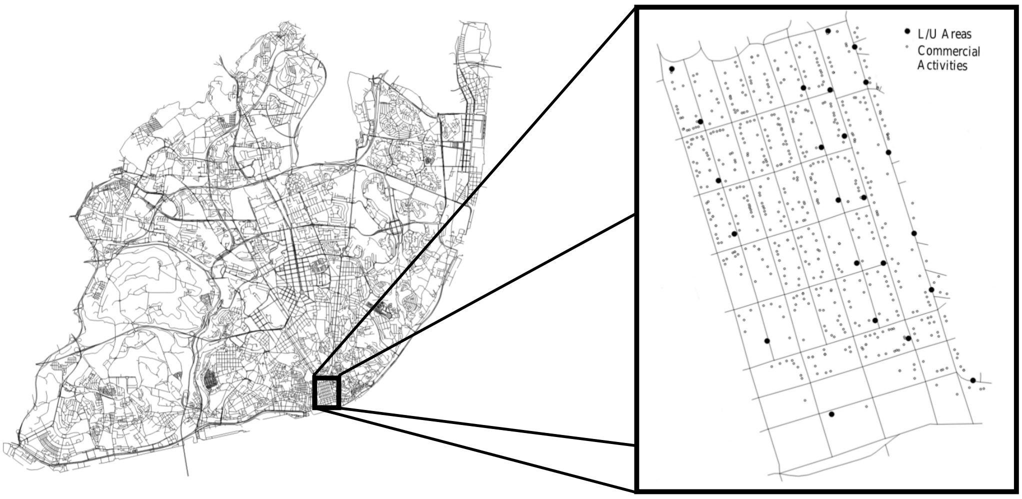
4 Results

In this section results are presented to assess the proposed approach. Firstly, the instance generation process is presented, then the solution method for the proposed approach is discussed, computational results are presented and, finally, **considerations on the acceptance of the system are reported.**

4.1 Instance generation

The proposed approach has been tested on the layout of the Lisbon city center, as the municipality has expressed the intention to find a way to reduce double parking and to promote a more efficient use of the areas. In particular, the focus is on the downtown neighborhood called Baixa, close to the river. We call Baixa the area delimited by Praça Dom Pedro IV and Praça da Figueira to the north, Praça do Comércio to the south, Rua da Madalena to the east, and Rua Áurea to the west (see Figure 2), representing an area of approximately 560 meters by 260 meters, some 14.5 hectares. In such neighborhood, 23 L/U areas have been placed over the years by the municipality, with the capacity of each area spanning from a minimum of 1 to a maximum of 8 spots, with an average of 3.26 spots per area. According to the 2010 census of commercial activities, 584 activities are located in the Baixa. For reference, according to OpenStreetMaps, the average walking time to one of those activities from the closest L/U area is about 40 seconds, and traveling by car between the L/U areas in the Baixa requires, on average, between 1 and 5 minutes, not accounting for traffic and traffic lights.

The data has been obtained through the open data websites of the city of Lisbon, in particular, the data from the commercial census is available at `http://dados.cm-lisboa.pt/en/dataset/recenseamento-comercial-2010`, and that of the L/U areas location is available at `http://dadosabertos.cm-lisboa.pt/dataset/emel`. The latter includes all on-street parking and L/U areas can be highlighted by selecting only the records with attribute “Tipologia” equal to “Cargas e Descargas”.



The road network of Lisbon

The L/U areas in the Baixa

Figure 2: The layout of the instances.

The instance generation process takes the following inputs:

- number of vehicles,
- number of areas,
- capacity of the areas,
- starting time of the vehicle,
- dwelling times,
- number of stops of the vehicles, and
- a deadline for the end of the bookings.

For ease of interpretation, tests have been conducted on instances with 10 areas of capacity one, with an increasing number of vehicles, i.e., $|K| = \{10, 20, \ldots, 100\}$. Five instances have been generated for each value of $|K|$. In total, 50 instances have been generated. Given the number of areas and the number of vehicles, for each vehicle the subset of areas to be visited is uniformly sampled between $\frac{1}{3}$ and $\frac{2}{3}$ of the total. The dwelling time of each vehicle at each of the selected areas is sampled uniformly in the interval [5,20] minutes. The starting time of each vehicle has been sampled in $[0, 300]$, with probability of 0.84 of being uniformly extracted in the interval $[0, 180]$ and probability of 0.16 of being uniformly extracted in the interval $[181, 300]$, which is equivalent to a preference for delivery in the first 3 hours 5.25 times higher than in the following 2 hours. These values reflect the results of a 2012 unpublished study for the Municipality, on logistical profiles of the various sectors in the city center, based on frequency of visits and duration of stays, plus those collected in 2018 by the authors in a survey to the distributors in the area. This survey was directed at the sectorial associations of deliverers active in the area, and included questions about the type of commercial establishments their members serve, how clients are grouped in the same route, how many clients are served in each route, typical times of day for those routes and length of each stay, and maximum walking distance acceptable. Replies were obtained from several associations in the catering sector, by far the most represented in the area. This was complemented with an interview with the association of shop keepers in the area, focused especially on the other sectors, with the aim of updating the 2012 information regarding frequency of visits and lengths of stay. No significant changes in this respect had occurred. The deadline D has been set to 600, representing 10 hours of operations in the L/U areas. Five scenarios have been sampled for each instance for the starting and dwelling times of each vehicle. The SEQ-semiflex approach has been tested with $f \in \{30, 60\}$.

4.2 Solution method

The framework to solve the booking problem with the sequential booking approach and to compare it to the current approach to L/U areas, represented by the independent TSP approach, has been implemented in Java with CPLEX 12.6 API and run using a machine with 3.5 GHz Intel Xeon E5-1650v2 processor and 64 GB of RAM.

Sequential booking

The solution of the sequential booking approach is obtained by solving as many routing problems as vehicles, in sequence. Before the model solution is computed for the k^{th} distributor, the time windows of each area are obtained by fetching the arrival and departure times of all the $k-1$ distributors that have booked a stop in that area and the consequent time intervals in which the area is not fully booked. This has been done for both variants of the TSP-MSTW. In both cases, the solution of each variant in the sequential booking approach has been obtained by solving the mathematical formulation with CPLEX, with computing time limit set to ten minutes. It is worth pointing out that computing times have proven to be negligible, with the solution of each TSP-MSTW requiring on average less than one second.

Independent TSP

The solution of the TSP of each vehicle in the independent TSP approach, reflecting the current state of the distribution, has been obtained with the Lin-Kernighan heuristic (see Lin and Kernighan [1973]), in the implementation provided by Helsgaun [2000]. In this case, because routes do not depend on whether spots are occupied or not, only the scenario with fixed starting times was considered.

4.3 Computational results

The results are reported as averages over the five instances generated for each value of $|K|$ tested. First, a general comparison of the approaches is presented. Then, a more detailed comparison is carried out for the instances with 70 vehicles, discussing the starting times of the vehicles, tour durations, double parking, and occupation of the areas.

Comparison of the approaches

A comparison of the different approaches is now reported. Results on the average tour duration and amount of double parking of the solution of each approach are shown in Figures 3 and 4, respectively. In Figure 3, the number of vehicles active in the system and the average routing cost in minutes are reported on the x-axis and y-axis, respectively. **The routing cost is defined as the time spent driving to a location or cruising for parking, i.e., the time interval the vehicle spends away from the depot minus the time spent parked at an area**. The dashed yellow line reports the average routing cost of the TSP tour for the vehicles in the independent TSP approach. The cost of the solution provided by the SEQ-fixed, computed as the average (for the five simulated scenarios) of the total time each vehicle has spent routing or waiting for an area to become available, is shown by the solid blue line. The dotted red line reports the same value for the SEQ-flexible and the two gray lines report the equivalent values for the SEQ-semiflex approach with the two tested values for f. Figure 4 shows the amount of double parking in minutes and the number of active vehicles on the x-axis and y-axis, respectively, for the same set of approaches.

The tour lengths, including the dwelling times, in the independent TSP vary between a minimum of 31 and a maximum of 109 minutes, with an average of about 69 minutes, independently of the number of vehicles in the system (as it was assumed that the capacity for double parking was unconstrained). It can be observed that the average cost of the solution provided by the SEQ-fixed increases strongly with respect to the number of vehicles delivering in the Baixa, to the point where, in the case of 100 vehicles, the average tour length in the SEQ-fixed is 294 minutes versus 165 minutes in the case of SEQ-flexible (see Table 1 for more details). The negligible difference found between the solution obtained when considering flexible starting times (SEQ-flexible) and the solution of $|K|$ independent TSP up to about 60 vehicles is very interesting result as it highlights a way double parking could be eliminated while keeping the routing cost of each vehicle comparable to that of an independent TSP solution with double parking. This approach, however, could have hidden costs due to the necessity of the distributors to consider the scheduling obtained for their operations in Baixa as a constraint in planning their operations in less constrained areas. These and other factors related to the acceptance of the sequential approach are discussed in Section 4.4. The SEQ-semiflex approach shows a similar behavior for both values of the flexibility parameter f tested. In particular, the performance of the approach shows a degradation rate comparable to the one of the SEQ-fixed. For both values of f the benefits of having some flexibility over the case where none is allowed (SEQ-fixed) are shown to stabilize for a number of vehicles greater than 40. With 100 vehicles, allowing a flexibility of $f = 30$ minutes allows for an average tour duration around 13 minutes shorter than the one of the SEQ-fixed. For $f = 60$ minutes, this benefit is about 40 minutes.

Given the similar results of the SEQ-semiflex with respect to the SEQ-fixed, we will not investigate further the results provided by the SEQ-semiflex approach as they have been shown to be close to the one of SEQ-fixed, meaning that they still impose quite high penalties on the tour durations of the distributors who book in the second half of the sequence.

An interesting result on the ability of the system to accept booking requests is presented in Figure 4. As reported, all the booking-based approaches are able to find solutions free of double parking with up to about 70 vehicles. This value represents the threshold beyond which no further requests can be accepted by the system and vehicles have to resort to double parking. This result, when considered jointly with the performance of the SEQ-flexible approach shown in Figure 3, provides an interesting evidence of the ability of the booking system to efficiently use the L/U areas to the point of the saturation of the system.

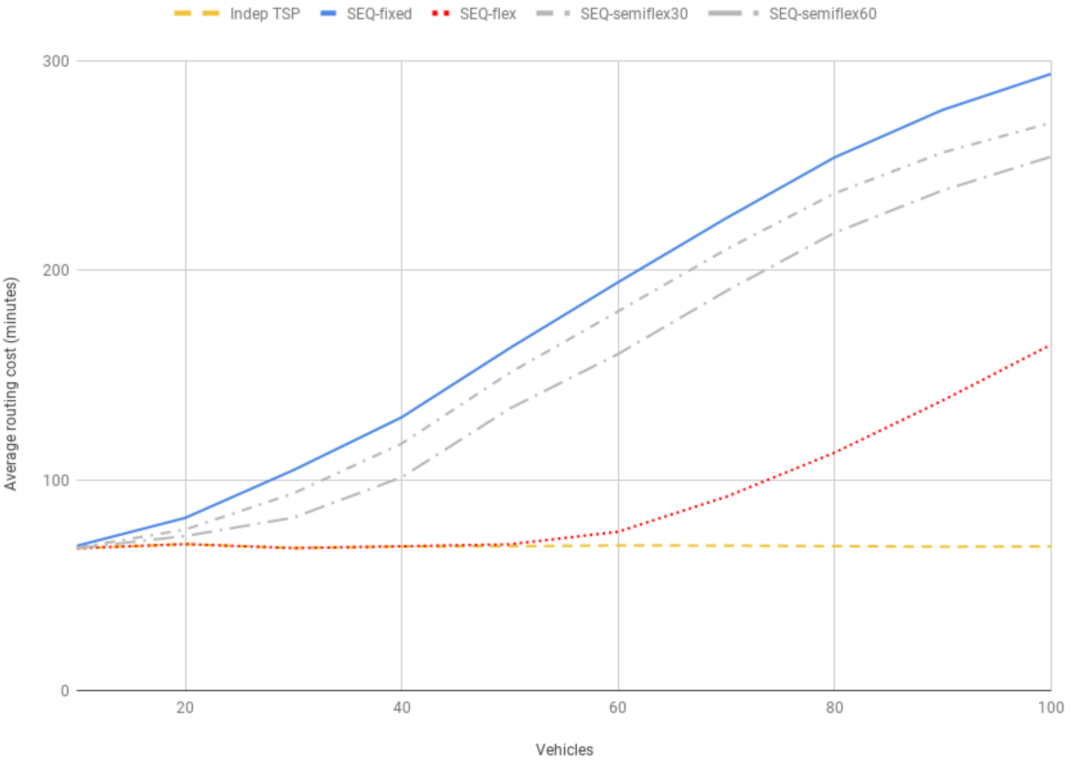


Figure 3: Routing costs (minutes).

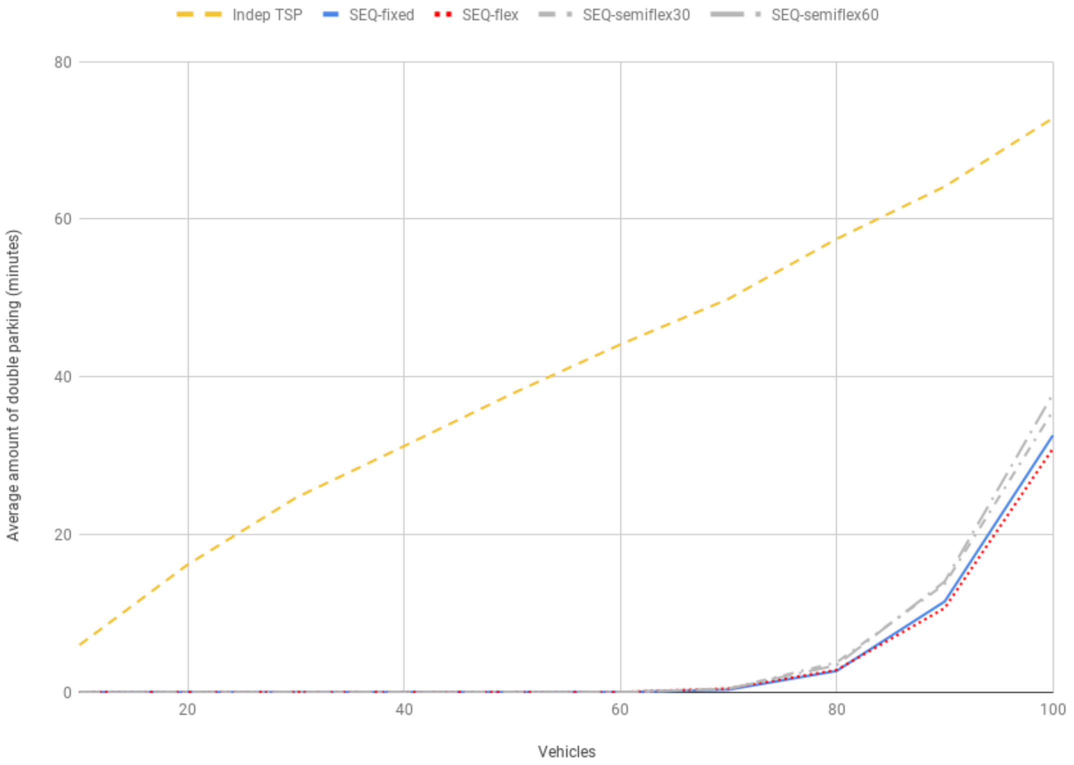


Figure 4: Double parking (minutes).

More detailed comparison of the approaches for the instances with 70 vehicles

To further investigate the performance of the proposed booking system when the infrastructure is correctly sized for the amount of requests it faces during the day, an analysis of a wider range of indicators for the instances with 70 vehicles is provided in the following. Instances with 70 vehicles have been selected as the largest for which the approaches are able to find solutions almost free of double parking, i.e., with less than 1% of the time spent double parking, even though in the SEQ-fixed approach a significant amount of idle time is wasted in the routes as seen in Figure 3. Unless otherwise noted, results are reported as the average among the 5 instances with $|K| = 70$ generated.

In Figure 5 the average starting times over the five scenarios are reported for the instances with $|K| = 70$ in classes of 15 minutes. The blue bars, representing the starting times of the vehicle in the fixed starting times case, reflect the instance generation process described in Section 4.1. The red bars, representing the starting times of the vehicle in the case of the SEQ-flexible, show a relatively uniform distribution throughout the considered distribution horizon, except for a peak at the beginning of the distribution (that could be partially caused by the symmetry of solutions with different starting times for the early bookers and the initialization of the parameters in CPLEX) and a downward trend toward the end of the distribution horizon, starting around the last time in which the average tour can end before the deadline.

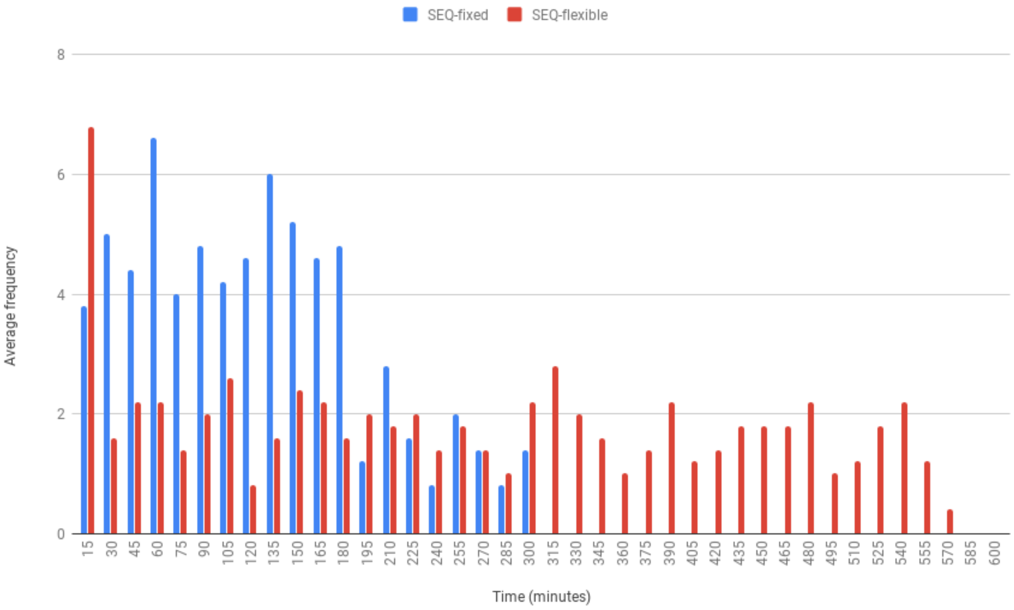


Figure 5: Average starting times of the sequential approach with fixed and flexible starting times.

Regarding tour durations, the results for the averages obtained across all 70 vehicles in the 5 simulated instances for each approach are shown in Table 1. As comments on the average duration of the tours have already been made above, we focus here on the variability of the reported values within each approach, expressed, for each approach, as the ratio over the result for the first ten vehicles booking. The ratio is reported for the middle ten vehicles, i.e. vehicles 31 to 40, and the last ten vehicles, i.e., vehicles 61 to 70. In the independent TSP approach, the ratio is always very close to one. This is the result for double parking, largely dissipating the variability of situations found on the demand side. In the SEQ-fixed the starting time is not flexible and this causes a strong and steady increase in the ratio, up to almost six times. While the SEQ-flexible also shows an increase in the ratio, this is limited to a very small increase (3.48 minutes or 5% of the total route length for the first 10 bookers) in the first half of capacity and then a stronger increase to almost three times longer tours for the late bookers compared to the early bookers. Furthermore, as shown in Figure 3, this increase is limited to the very last vehicles booking.

	Indep. TSP	SEQ-fixed	SEQ-flexible
Vehicles 1-10	1.000	1.000	1.000
Vehicles 31-40	1.046	2.985	1.051
Vehicles 61-70	1.012	5.929	2.841

Table 1: Ratio of average tour durations over the duration for the first 10 vehicles for each of the approaches in the $|K| = 70$ configuration.

The amount of double parking in the independent TSP solution is presented in Figure 6, where the number of vehicles double parked over time is reported for the instances with $|K| = 70$. A peak is observed around the $[70, 190]$ time interval, with generally more than ten vehicles double parked on average. Peaks of more than 13 vehicles double parked (more than 1.3 vehicles per area) is observed around the 90^{th}, 120^{th}, and 170^{th} minute marks. This result reflects the joint impact of the distribution of the starting times (as shown in Figure 5) and the duration of the tours.

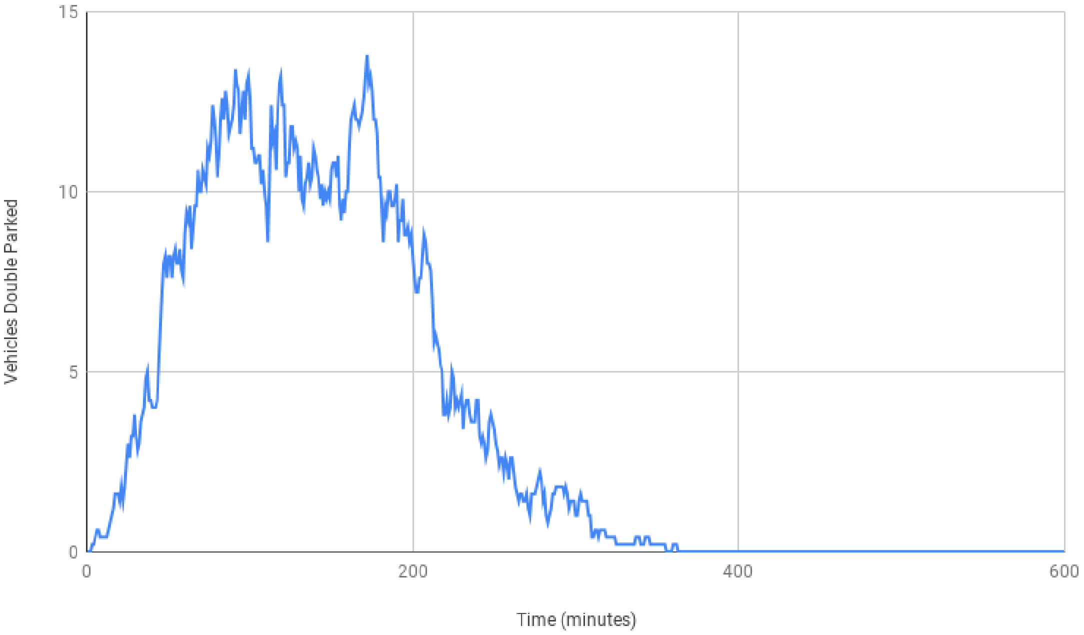


Figure 6: Average number of double parking vehicles over time in the intependent TSP approach.

Occupation analysis

Figure 7 reports the evolution of the average used capacity ratio of the system over time for instances with 70 vehicles, with starting times as shown in Figure 5. The curves show the ratio of used capacity in the past 5 minutes interval, e.g., at the 100 minute mark, the solid blue curve shows, for the SEQ-fixed, the average used capacity ratio of the system between minutes 95 and 99. For the case of the independent TSP approach, this graph shows a curve with values between 75% and 90% between minutes (roughly) 60 and 210, in correspondence with the preferences for starting times and tour durations. While this result appears to be comparable in that period with the one of the sequential approach with fixed starting times, the curve only considers the parking taking place in legally defined L/U areas, thus it must be considered jointly with that shown in Figure 6, showing a higher incidence of double parking roughly in the same period. For the sequential booking approaches, this graph shows how, when fixed starting times are considered, the occupation level over time reflects the fact that earlier starting times are more requested by the distributors with the occupation level generally between 75% and 90% in the $[60, 500]$

time interval, with a peak up to 91%. When a flexible starting time is considered, each vehicle minimizes its routing costs without being constrained by a predefined starting time. This leads to a more uniform occupation of the areas over the entire time horizon, with the occupation ratio generally around 75% in the [50, 570] time interval.

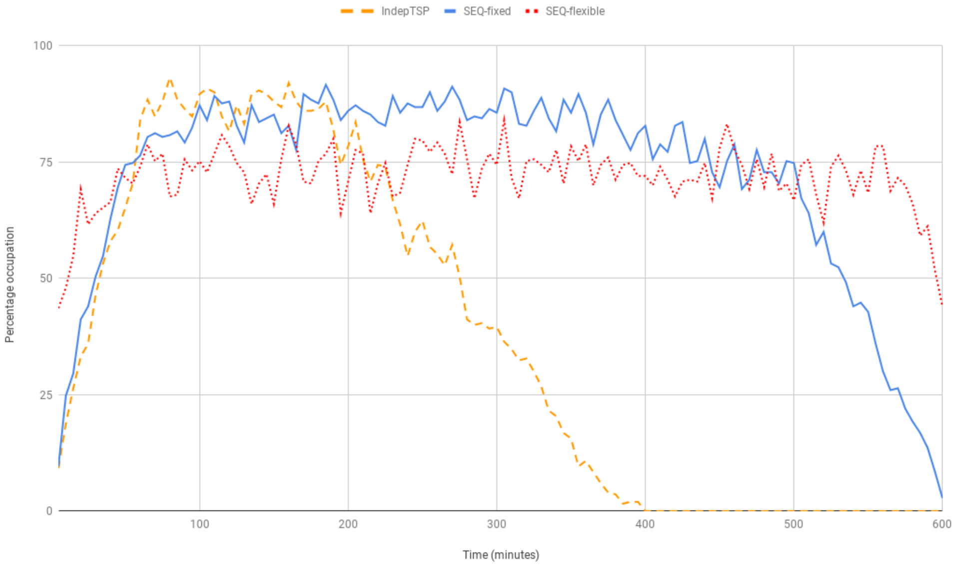


Figure 7: Used capacity of the L/U areas in five minutes intervals.

4.4 Acceptance of the system

The management of L/U areas through a booking system would require the involvement of all the stakeholders (customers, distributors, municipality, traffic police) and their acceptance that it is in everybody interest for the system to perform well as it allows for less discomfort both in terms of delivery delays and traffic flow. In the early stages of adoption the traffic police would have to be on top of the new system, educating any distributor that comes with an unregistered vehicle or without booking about the new rules for the use of the L/U areas. Information to the stakeholders could be provided via web (and possibly in a few meetings) to share some statistics of adoption of the system, of occupation of the delivery positions across the hours of the day and days of the week, and check on the problems each category is having on the use of the system and study corrective actions.

The sequential booking approach seems to offer many benefits. Most prominently, it provides a way to eliminate, or at least substantially reduce, the double parking arising from the use of L/U areas with little economical and implementation costs to the municipality. In its fixed starting time form, it lets the distributors retain their ability to define the starting time of their route into the city center and the sequence of their visits but, as seen in Figure 7, quite quickly (in terms of the number of vehicles active in the system) imposes large stopping times waiting for the desired slot to be available, which is something very difficult to solve in practice without falling into a problem of the same kind of double parking (but with the delivery activities suspended, which would be even worse). Furthermore, it must be said that the issue of where the vehicles would be in the waiting periods between deliveries, which is particularly relevant in the SEQ-fixed approach, has not been considered. The cost of waiting is almost completely eliminated in the approach with flexible starting times, i.e., if the distributors can arrange the availability of the vehicle to reflect the starting time obtained through the solution provided by the optimization model. This arrangement, similar to what happens with people looking for a medical appointment or a table at a popular restaurant, imposes adaptation costs, which in this case may impact on the sequence and times of the loading operations and the working hours of the drivers. This can be seen as a fair price to pay in exchange for a system that ensures available L/U spots at the reserved times and a total tour duration as in a “selfish” approach, but within a framework of respect for the road space, namely avoidance of double parking. Ultimately, this is similar to what already happens in many cities where municipalities have defined "low emission zones" and in which quite narrow time windows are defined for L/U operations. The difference is that, in those cases, the time windows for the delivery tours are the same for all distributors (thus concentrating the demand and not solving the double parking zone) while in our approach each distributor gets a specific time window for its delivery tour. The obvious benefits that could be obtained at the tactical level by the booking system are complemented by the benefits at the strategic level, possible thanks to the information generated by the implementation of the booking system and the daily information about saturation levels of the L/U areas, across space and across the hours of the day.

The definition of the route is left to the distributors, allowing them to include specific delivery time constraints, subject only to having the system check for the feasibility of the travel times between successive delivery stops. Early bookers and late bookers might have different requirements and behavior when solving their routing problem. Early bookers could exploit the greater availability of parking space to solve more complex and integrated problems, while the late bookers would need a different approach to deal with the difficulty of finding ways to visit the required areas (perhaps also postponing some visits to a later date). A good part of the distributors (possibly with the exception of those booking early) could also use the system in a hybrid mode, defining their hard constraints (for instance due to time windows imposed by certain clients), while checking for their feasibility in terms of available spots, and asking the system to optimize the rest of the route in a pattern that is compatible with the available spots. Clearly, the preferred configuration of the system in each city would be an outcome of the dialogue between the municipality and the multiple stakeholders involved in the urban logistics system.

5 Conclusions and further research

In this paper a booking management system has been introduced to deal with the issue of double parking in the L/U areas of a city center. In this booking system, distributors place their bookings in sequence, similar to the dynamics of the bookings in other areas such as restaurant bookings or doctor appointments. This and other factors discussed in the paper contribute to make the sequential booking system an approach that could be tested in a real-life case with relative ease. Considerations on the acceptance of the system have been made. Computational results have shown that compliant routes with cost close to that of an independent solution with double parking can be achieved if the distributors are able to plan for the vehicle to have a flexible starting time, under the assumption of the system being properly sized w.r.t. the amount of demand of L/U operations. The reported experiments have also provided a way to assess such proper sizing.

Further research could deal, at the tactical level, **with the additional complexity faced when the recipients of the goods are considered. This would allow for the consideration of client-defined time windows and how they could be most efficiently included in the proposed approach and for the efficient selection of the most appropriate set of areas to stop to perform the delivery to the recipients by foot. At the operational level, further research could focus on including in the system the uncertainty associated with the variability of actual delivery times and of traffic speeds. Some learning component could be also included in the system so that connection times between each two L/U areas at certain times of the day and days of the week can be regularly updated.**

Acknowledgments

The authors would like to thank the anonymous reviewers for their valuable suggestions and comments which helped improving an earlier version of this paper.

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