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Parking slot assignment for urban distribution: Models and formulations ☆

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ABSTRACT

A key element to enhance urban distribution is the adequate management of parking space, particularly for loading and unloading operations. An in-advance booking system able to be adjusted to users needs can be a very useful tool for city councils. Such a tool should be fed with criteria for allocating requests to time slots. In this paper we discuss alternative criteria for the parking slot assignment problem for urban distribution and we propose the use of mathematical programming formulations to model them. Several models are proposed, analyzed and compared among them. Extensive computational experience is presented with a detailed analysis and comparison, which provides quantitative indicators of the quality of each of the proposed models.

1. Introduction

Major cities face multiple problems caused by delivery operations in urban distribution. In many cases city councils regulate the conditions under which carriers may operate, and then each carrier acts as his own decision maker, scheduling his operations according to established rules and his own resources' limitations. In contrast, city councils must act as joint decision makers for all operations that must be carried out with the use of public space, since a criterion on how to allocate public space among carriers is needed. The adequate management of public space is crucial for successful urban distribution. The lack of parking facilities has been pointed out among the aspects with higher impact in urban delivery (see, for instance, [1]). This paper deals with the problem of allocating public parking space in the streets during the loading and unloading hours for goods distribution from an operations research perspective. The use of operations research in urban planning has been discussed in [2] in contrast to interactive city planning, reacting to events as they occur [3].

A general framework for the problem that we address is the following. The goal of the city council is to regulate the use of public space in order to prevent carriers from parking illegally and to improve urban distribution. To this end a system is proposed in which carriers can only park at designated parking areas and designated time periods, which are assigned in advance by the city council. Such a system would eliminate the very negative effects in traffic flow due to carriers double parking and would also benefit carriers greatly, since available parking space would be guaranteed at designated time periods. For this, some public space, consisting of a set of parking places, is allocated for loading and unloading operations at a given area during some hours each day. The city council asks carriers to express in advance their requests for a parking time interval and to inform about the duration of their operations. These durations will take into account not only loading and unloading activities but also movement times between the parking space and the operation site. Then, each carrier is assigned a time interval, based on his preference. Since carriers will know in advance their assigned time interval, they will be able to re-optimize their routes beforehand so as to arrive on time to the assigned parking space. Thus, we assume that carriers will accept and respect the assigned intervals, even if they do not fit their requests (Fig. 1).

Several works point out the advantages of allocating specific parking facilities for carriers in order to reduce the negative impact of distribution operations. As an example, the results of [4] illustrate the positive response of most drivers and truck operators to one such initiative in Kobe (Japan) in 2001. It is however clear that, even if a set of parking places is allocated,

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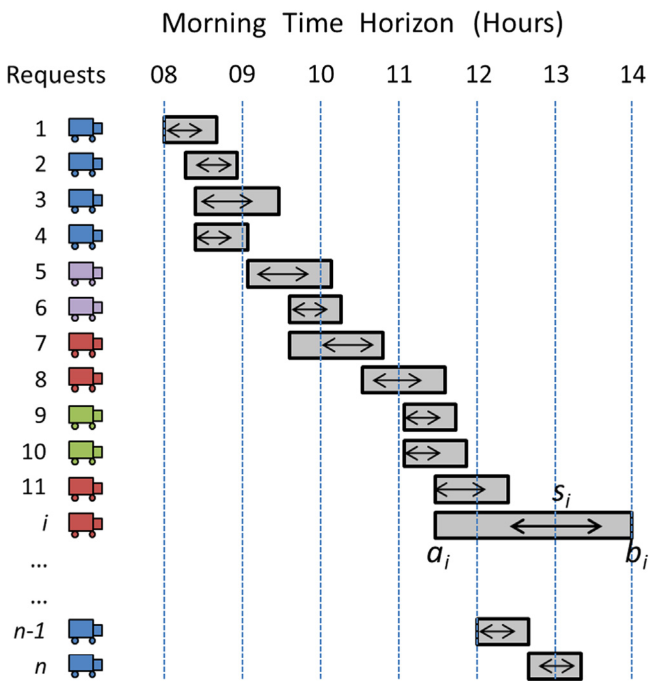

Fig. 1. Requests of different companies along morning time horizon.

negative effects will prevail when carriers arrive to delivery areas but find no available parking space. The benefit of establishing some booking system for allocating in advance places has been assessed in several practical studies. The results of a pilot test carried out in 2005 in Dos Hermanas, Sevilla (Spain) [5] confirm the effectiveness of the internet booking system implemented for the assignment of parking space in load areas of the city center. An advanced booking system was theoretically studied in [6] for the city of Winchester (UK) in the Highstreet area. Supported by an EU project [7], a recent eight months pilot test in Bilbao (Spain) successfully trialled a booking system for carriers in four zones of the city. Free areas could be assigned to users without pre-booking, and pre-booked carriers could be reassigned if they were out of schedule, as well.

In the above referenced works priority lists have been used for deciding the assignment of places to requests. However, alternative criteria or techniques can be applied for establishing the allocation of parking space to carriers. In this paper we propose the use of mathematical programming optimization models for solving the parking slot assignment problem. To the best of our knowledge this problem has not been addressed so far in the literature in the context of urban distribution. Nevertheless, we can find some similarities with other problems studied in the literature. For instance, the problem that we address can be seen as a particular case of a scheduling problem with time windows (see, for instance, [8]). Further, the concept of earliness/tardiness, as it has been used in scheduling problems with time windows [9,10] or other contributions in flow shop scheduling problems based on the manufacturing industry [11,12] can also be exploited in our case as we will see later on.

Problems like the Berth Allocation Problem (BAP) [13], the Aircraft-Gate Allocation Problem (AGAP) [14], or the allocation of trains to platforms at rail stations (Train Platforming Problem [15]) also have some similarities with the Parking Slot Assignment Problem (PAP). In all these problems it is assumed that the arrival times of the vehicles as well as the durations of their operations are known in advance, and the vehicles have to be assigned to some facility for a given time. The BAP aims to optimally schedule and assign vessels to berthing areas along a quay. The most common objective in the BAP is to minimize total service time. This objective favors the assignment of higher priorities to vessels with smaller handling volumes than to vessels with larger handling volumes [16]. Because this type of solution may not satisfy the ocean carrier' preferences, another studied objective is the minimization of the deviation from the preferred berth [17]. Some other works consider, in addition, objective functions with penalties for unsatisfied time windows [18]. Similar characteristics are present in the AGAP [14], in which the gates where aircrafts will stop are planned taking into account different criteria: efficiency of flight schedules, passenger walking distance, or robust use of the gates in front of disruptions [19]. The distinctive feature of the PAP with respect to the above problems is that the carriers' time windows are flexible, in the sense that the parking times assigned to the carriers by the city council may not coincide with the requested ones. Still we assume that carriers accept and respect the assigned intervals, provided these are known in advance. The reason for this assumption is that carriers can adapt their routes in advance so as to arrive on time to the assigned parking space. This assumption does not hold in the BAP, the AGAP or the allocation of trains to platforms, whose time windows are not flexible and thus must be respected when making the assignment. In the BAP, while advancing the arrival date to port is usually not feasible, postponing it typically implies very high costs. The same happens with the departure dates from the port due to contractual agreements between port operators and ocean carriers. Something similar happens with aircrafts, where indeed flight schedules are not planned according to the availability of gates at the airports.

The main question that we address in this work is the criterion that should be optimized. Given that the goal of the city council is to avoid illegal parking, and carriers would greatly benefit from having a prebooked parking space, any solution satisfying all requests within their time windows would be optimal. From this point of view, one would think that the problem we face reduces to a feasibility problem. However, a given instance may not have an assignment satisfying all requests. What should the outcome be in this case? What can the decision maker do if there is no parking slot for everyone? Some fair criterion is needed in order to allocate carriers' requests when their needs cannot be satisfied. Several modeling alternatives are proposed and compared in this work, in which we restrict to one single loading and unloading area with several parking places. Each of these alternatives aims at optimizing a different criterion, which may seem appropriate for finding compromise solutions for the parking allocation problem. First, we propose a mathematical programming formulation for the feasibility problem under consideration and introduce the alternative models based on different optimization criteria. Then, we study some relations among the different models and give a sufficient condition for unfeasibility of the basic model. Afterwards, we carry out a thorough comparison, based on the results of an extensive computational experimentation, which provides quantitative indicators of the quality of each of the proposed models.

In this paper we assume that data is deterministic. This is indeed a simplifying modeling assumption as the nature of the problem involves some uncertainty, particularly with respect to vehicle arrival times. However, as we will see, the deterministic formulations proposed are already complex and difficult to solve.

The remainder of this paper is structured as follows: Section 2 formally introduces the problem and presents a mathematical programming formulation for the feasibility problem as a mixed integer problem (MIP). Section 3 presents the different alternative models that have been considered, and studies some of their properties. Section 4 describes the computational experiments we have run, and presents the obtained results together with an extensive analysis and comparison, and Section 5 presents a simple heuristic and compares its solutions with those obtained previously. We close the paper in Section 6 with some comments and possible avenues for further research.