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Loading/unloading lay-by areas location and sizing: a mixed analytic-Monte Carlo simulation approach

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Abstract: The already significant volume of freight vehicles moving within city limits is steadily growing, and is expected to continue increasing at an even faster rate. Many European cities, however, have historical urban heritages and constraints that make them a logistics nightmare, where traffic congestion can result from improperly parked vehicles. In this paper, we focus on the location and sizing of commercial parking lay-bys in urban centres, where it is possible to park for a limited amount of time to perform loading/unloading operations and deliveries. The problem has been formulated and addressed with reference to a central district in the city of Bergamo, with a strong commercial presence, and characterized by significant problems of traffic congestion. We present a mixed analytic-Monte Carlo simulation approach in order to find an optimal distribution and relative sizes of the lay-by areas according to the demand and location of the business activities.

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1. INTRODUCTION

The distribution of goods in urban areas constitutes both an extremely important and a rather disturbing activity. It ensures supplies at stores as well as delivery of goods at home, providing a vital link between suppliers and customers (Crainic, et al., 2004). Yet, freight transportation is also a disturbing activity because of the significant contribution to congestion and environmental nuisances, such as emissions, noise, and so on. The already significant volume of freight vehicles moving within city limits is steadily growing, and is expected to continue increasing at a faster rate. Such a substantial growth is rooted in many factors: from the recent push towards inventory policies emphasizing the reduction of space for storage to the increase of the number of *e-tailers* generating significant volumes of home deliveries.

Furthemore, urban population is steadily growing: in Europe more than 75% of the population lives in the urban agglomeration which are the destination and sometimes the origin of the flows of goods (Dezi, et al., 2010). This phenomenon carries a manifold increment of demand for goods and services, mainly concentrated in relatively limited areas. This is inevitably leading cities around the world to face increasing challenges in terms of efficient transport activities while controlling and ideally reducing their negative impacts on the quality of life (Benjelloun, et al., 2010).

To deal with the issues arising in urban freight transport, city logistics projects usually focus on three main areas: *i*) the reduction of traffic congestion and interference; *ii*) the reduction of pollution factors related to the distribution of goods, primarily (but not exclusively) through the use of low-emission or clean (e.g. electric, natural gas) vehicles; *iii*) the reduction of indirect costs related to the distribution of goods, for example, reducing the risk of accidents through a reduction in the number of vehicles in circulation. In this paper, we focus on the first area, dealing with the location and sizing of loading/unloading lay-bys (also referred to as commercial vehicle parking areas or commercial loading/unloading zones) in urban centres. As shown in the remainder, this piece of infrastructure (especially, the lack or incorrect design thereof) can have a substantial influence on the traffic flows and on the efficiency of the urban freight and transport service system. Therefore, in this paper we present a mixed analytic-Monte Carlo simulation approach in order to find an optimal distribution of the lay-by areas according to the demand and location of the business activities. Our model has been tested on one area inside the city of Bergamo (Italy).

1.1 Motivation of the study

Many European cities have a historical urban heritage and urban constraints that make them a logistics nightmare; unlike the so-called *pop-up towns* born from greenfield, for example in China, EU cities are characterized by their historical configurations, and are often ill-suited to accommodate an increase of traffic flows in urban centres. Freight transport in urban areas is difficult to optimize being interwoven with the context in which it operates (Lagorio, et al., 2014).

Moreover, a recent survey in the city of Bologna (Italy) reported that more than 85% of the stops by commercial vehicles for loading/unloading operations are in non-dedicated areas or even in double-parking (Dezi, et al., 2010).

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Resorting to double-parking affects the traffic flow in the area, generating congestion and access problems, particularly acute in the central districts of the city. Hence, the need to establish a location and management model for the lay-bys in the city, reconciling two conflicting goals: on one hand, the need for ensuring an efficient distribution of goods (even considering the requests for frequent and small delivery from retailers that operate a just in time policy). On the other hand, the necessity to regulate freight traffic to minimise the environmental impact and the hindrance to traffic flows (Maggi, 2001).

Thus, the location and management of commercial lay-bys within the city aim at achieving two different goals: *i*) economic efficiency in the delivery of goods, and *ii*) enhanced social welfare achieved by reducing the hindrance to the traffic flow caused by irregular parking practices. To this end, the paper is organized as follows: in Section 2, we provide some background information to frame the context and the elements of the research. In the same section, we also outline the case study considered in our study. Section 3 briefly illustrates the proposed approach, while in Section 4, we introduce and discuss the formulation of the analytical model and the simulation model used in the research. In Section 5, we report some numerical results, and we conclude the paper in Section 6 providing some conclusions.

2. BACKGROUND AND CASE OUTLINE

The location and management of the commercial lay-bys involves several aspects. In summary, we can mention the following main tasks:

- Identification of the number and location of the lay-bys in the city. Regarding this aspect, it is important to consider the distance of the points of delivery (i.e., shops, retail points mainly, but also private demand points for the delivery of e-commerce purchases) from the lay-bys. A good location plan of the lay-bys should ensure the proximity of at least one lay-by to each delivery point.

- Identification of the number of parking stalls in each lay-by. A parking stall represents the physical space that a commercial vehicle can occupy in the lay-by area. In general, we consider a common stall size (i.e., about 6 m × 2,5 m) as defined by the National Road and Highway Code, able to host light commercial vehicles and small trucks used for the delivery in the city. The number of stalls determines the number of commercial vehicles that can simultaneously park in a lay-by area.

- Definition of the management policy for each lay-by. This aspect encompasses some further elements: first, the definition of the time window during which the lay-by is reserved for commercial vehicles. In some cases, in fact, a lay-by can be reserved for commercial vehicles for a portion of the day (i.e., from 7:00am to 10:00am) whereas if free for other vehicles outside that time window. Secondly, the possibility to effectively reserve a stall for a given period, for example using a mobile app such as in the Area DUM project in Barcelona (Area DUM, 2015). This aspect opens up the problem of enforcing the reservations against the risk of unauthorized occupation.

The interaction of all the above mentioned elements makes the overall problem complex and difficult to address with a single, all-encompassing method.

To provide further evidence to our discussion, we refer from now on to the specific piloting area subject of the study. The problem of the location of parking lay-bys has been addressed with reference to a central district of the city of Bergamo, with a strong commercial presence, characterized by significant problems of traffic congestion (Fig. 1). The considered area covers about 0.22 km2 and encompasses 162 commercial activities (i.e., an average of 736 commercial activities per km2).

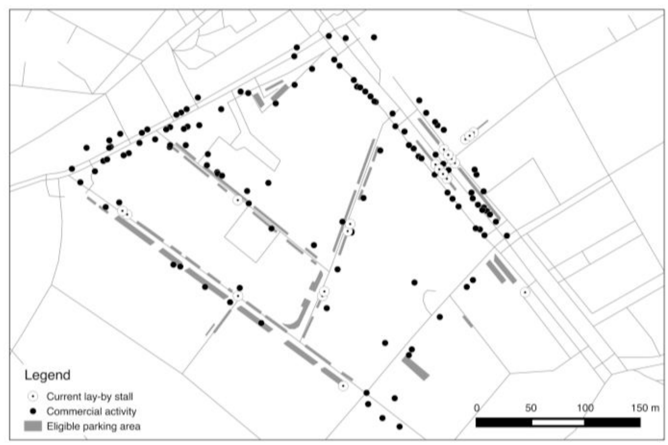

Fig. 1. Area of the pilot study.

2.1 Data collection

Modelling the complexity of urban freight transport requires large amounts of data related to supply chain management, delivery practices, tour configuration, time windows and so forth (Muñuzuri, et al., 2010). Transport companies, operating in a very competitive environment, are normally reluctant to provide data on shipments, tours or timetables, which are viewed as commercially confidential (Morris et al., 1998). Thus, the collection of data to represent and model urban freight deliveries is an expensive and difficult task.

Due to the goals of the research, we required two categories of information:

- Spatial information: information about the position of each business activities in the pilot area, and information about the position of zones able to host lay-bys parking areas.

- Business information: information about the requirements of the business activities in the pilot area regarding their needs in terms of number and frequency of deliveries, and time required for loading/unloading activities.

While for the spatial information it was possible to resort to Geographic Information Systems (GIS) and commonly available maps, the category of business information required more effort. For a sample of the business activity present in the pilot area and requiring delivery by means of commercial vehicles needing to park on a public space (i.e., on the road or in public parking stalls), we interviewed the store managers to better understand their business requirements.

Finally, an on-field inspection of the area under study allowed us to validate the information retrieved from the GIS and the maps. In particular, the on-field inspection allowed us to fill gaps and errors, especially for the identification of the parking zones that may be destined to host a lay-by (Fig. 1). In doing this, we also considered urban planning and physical constraints that were not detected from the maps.

3. PROPOSED APPROACH

As already mentioned in the previous section, the interaction of all elements involved in the analysis makes the overall problem complex and difficult to address with a single, all-encompassing method. Therefore, we decide to decompose the problem in two stages, each addressed using a specific method. Indeed, the study of the locations of the lay-bys may be addressed as a facility location problem on a long horizon (i.e., once the lay-by areas have been positioned, they are unlikely to be subject to repositioning in the short term), whereas the occupation of the parking stalls implies the analysis of the dynamics of the commercial vehicles parking requirements over time.

In summary, we structured the analysis in two stages:

- The first stage addresses the design of an analytical model allowing the identification of the location of the lay-by areas. In this case, an analytical model is suitable since the location of the lay-by areas is based mainly on spatial information, which is deterministic in nature (i.e., not subject to variability).
- The second stage addresses the analysis of each lay-by area activated selected by the analytical model at the first stage to assess the most suitable size (i.e., number of parking stalls) ensuring acceptable performance in terms of space occupation and parking availability. In this stage, the main information used is the demand of the commercial activities; this information can be subject to variability in terms of magnitude (i.e., number of deliveries per day) and over time (i.e., from one day to another, or from one season to another). Therefore, we opted for a simulation model in order to assess the performance of this design decision.

In our research, we decided not to address the routing decisions or the interaction with other urban flows. In fact, we focus on the location of the lay-by areas and the number of stalls for each area considering the current requirements from the business activities. In the next section, we define and discuss the models supporting the above-mentioned two-stage analysis.

4. MODELS FORMULATION

4.1 The location model

To define the best locations for the lay-by areas, we adopted a discrete covering model. The model aims at finding the minimum number of lay-by areas that can “cover” all the delivery destination points (i.e., shops and retail points), where a point is considered covered if there exists a lay-by area not farther than a distance R, called *radius*. In general, the radius represents the longest distance that a delivery operator is willing to walk (on a straight line) from the lay-by area to deliver the goods. Such an approach requires the following steps:

- From the spatial information and the field inspection, we identified the areas (in general at the borders of the streets) potentially eligible to host a lay-by area. In general, the parking areas are considered with their coordinates in the continuous space (Easa & Dezi, 2011). We opted for a discrete model, which allows for a simpler formulation, with low impact on the accuracy of the location. To this end, we discretized each eligible area in a finite number of homogeneous lay-by areas, each identified by the location coordinates of its geometrical centre (Fig. 2).

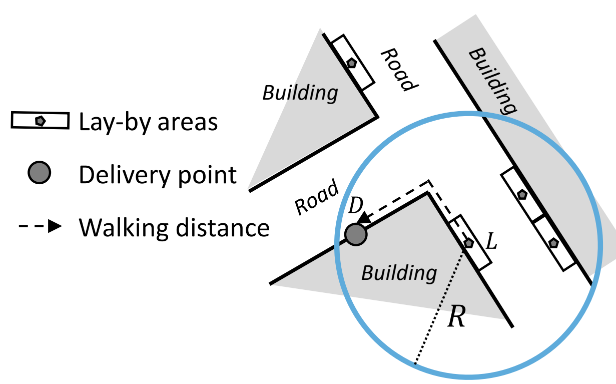

Fig. 2. Covered area vs real walking distance.

- The notion of coverage should be adapted to the constraints of the field. In fact, with reference to the example reported in Fig. 2, it is not correct to consider covered a destination point within the circle of radius R and centred in the lay-by area; we have to consider a point covered if it is within a walking distance of R meters (i.e., real walking distance) from the centre of the parking lay-by. In Fig. 2, the delivery point D is, thus, not covered from the lay-by L.

Given these assumptions, the covering model can be described as follows: given a set N of delivery points and a set M of feasible lay-by area locations, we want to define the minimum number of locations in M where a lay-by should be placed. A location selected for placing a lay-by is called *active*. The final objective is to cover all the delivery points in *N*. Formally, a delivery point $i \in N$ is covered if there exists at least one active location *j* such that the walking distance *d*(*i,j*) between *i* and *j* is shorter that a pre-specified distance *R* (still called *radius*). We can represent the covering possibilities using a binary matrix *C=N×M* whose entries are defined as follows:

$$c_{ij} = \begin{cases} 1 & \text{if } d(i,j) \le R \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

The formulation of the model requires the definition of the binary variables $y_j \in \{0,1\}$, which assumes the value 1 if a lay-by is placed in the location $j \in M$, and 0 otherwise. The objective function is, therefore:

$$\min \sum_{j \in M} y_j \tag{2}$$

and the covering location model is obtained adding the following constraints:

$$\sum_{j \in M} c_{ij} \cdot y_j \ge 1 \qquad \forall i \in N \tag{3}$$

In fact, all the delivery points $i \in N$ must be covered; this means that, among all the lay-by possible locations $j \in M$ within a distance *R*, at least one should be activated (i.e., $y_j = 1$). Clearly, it may result that some delivery points are covered by more than one parking lay-bys, whereas uncovered delivery points are not allowed. This may result in cases where isolated delivery points require their dedicated lay-by area. These corner cases can be subject of further cost-benefit analysis to exclude them or confirm the solution.

The result on the pilot area suggests to activate nine lay-by areas, considering a walking distance *R* = 75 m, slightly shorter than *R* = *100* m stated in the literature (McLeod and Cherrett, 2011) because of the relative small size of the considered area.

The formulated covering model does not distinguish between the size of the delivery required by each delivery point (i.e., all delivery points must be covered, regardless the amount of goods they should receive). This assumption is coherent with the initial requirement to cover all the destination points defining both the minimum number and location of parking lay-by areas. In case the number of parking lay-by areas to be placed is limited, the model can be easily adjusted introducing a different objective function requiring to cover the maximum amount of "demand" (*maximal covering problem*).

4.2 Definition of the number of parking stalls per lay-by area

Solving the covering model allows defining the locations of the lay-by areas required to cover all the delivery points. As a further result, it is possible to associate each delivery point with a unique lay-by area. However, the described model is not suitable to define the number of stalls to be placed in each active location.

The definition of the correct number of parking stalls to be placed in each location is influenced by several parameters, such as *i*) the number of delivery points served from each lay-by area; *ii*) the number of expected delivery trucks per delivery point per day; *iii*) the time-window available for the loading/unloading operations (i.e., from 7:00 am to 10:00 am, or the whole day); *iv*) the average duration of the loading/unloading operations; *v*) the possibility to reserve the stalls in advance, thereby scheduling the arrival of the trucks.

The covering model allows to define only the first parameter (i.e., the number of delivery points served from each lay-by area), whereas all the others may be subject to some degree of uncertainty, or even not known at all.

If the parameters are known (at least, their average values) it is possible to define an average number of stalls per each lay-by area. For example, let us consider one lay-by area $k \in U \subset M$ (that is, *U* is the subset of active locations in *M*). Let us define the delivery window T_k, the average duration of the loading/unloading activities t_k, the number of delivery points n_k served from the lay-by area *k*, and the average number of trucks v_k required by each delivery point served from lay-by area *k*. Let us assume that it is possible to schedule the arrival of each truck, so it is possible to avoid conflicts in the occupation of the parking stalls within the lay-by. In this ideal situation, the number S_k of stalls to place in the area *k* is given by:

$$S_k = \left\lceil \frac{t_k \cdot n_k \cdot v_k}{T_k} \right\rceil \tag{4}$$

where the operator $\lceil x \rceil$ indicates the rounding up to the nearest integer of the number *x*.

However, in many cases, some of the parameters defined above are uncertain, or there may not be the possibility to schedule the arrival of the trucks, thus making necessary to deal with stochastic arrivals and performance. To deal with this aspect, we need to assess the performance of the design decision about the number of stalls under different conditions. To this end, we formulated a simulation model, as described in the next subsection.

4.3 Assessing the solution performance: the simulation model

Simulation is a well-known approach suitable to deal with uncertain parameters. There are different simulation paradigms that may be used in this context. For example, Boussier et al. (2011) used an agent-based simulation approach to assess the performance of a strategy based on the sharing of parking places between light cars and vans for goods delivery. The authors have also shown that the implementation of behavioural models and learning process of cognitive agents based on stated preferences collected beside the network users are designed for capturing multi-agent interactions. Cortés et al. (2007) used discrete-event simulation to analyze the freight traffic in the Seville inland port, focusing on the transport process through the estuary and its arrival to the port dependencies including the loading/unloading processes by the logistics' operators. Similarly, van Duin et al. (2014) adopted discrete event simulation to analyze the logistics performances and traffic influences for different fleet size configurations of different vessels types (touring boats, pleasure crafts and freight vessels).

According to the specific goals, modelling the complexity of urban freight transport usually requires large amounts of data. In our case, however, we were interested in the assessment of the performance resulting from a design decision about the number of parking stalls to place in each lay-by area. Thus, we decided not to address higher level decisions, such as for example the routes of each commercial vehicle, or the interaction at the traffic level with other transport services (i.e., public transport). Further, in the analysed case, we can simulate each lay-by area separately from the others. The reason underpinning this opportunity is that once the parking lay-by areas have been optimally placed, each driver will naturally drive to the closest location (unique in general, although a delivery point may be covered by more than one lay-by area), thus reducing or even eliminating the interactions with the other locations. On the basis of these considerations, we opted for a process-based Monte Carlo simulation paradigm, which requires less information and computational effort. The Monte Carlo simulation consists in producing thousands of scenarios (also called iterations or trials) sampling from the probability distributions of the events that can occur (Vose, 1996). In our case, an event can represent the arrival of a truck requiring a parking stall, or the duration of the loading/unloading operations, or even the number of trucks expected to visit a given lay-by. Monte Carlo simulation is most useful when it is difficult or impossible to use other mathematical methods; in the considered case, in fact, the analysis via analytical methods is very complex. We simulated the decision process of the drivers, summarized in Fig. 3. When a driver arrives at the lay-by area, there are two basic alternatives: either one stall is available (so the driver can park and perform the delivery), or are all occupied. In the latter case, the driver can decide to *i*) wait for a stall becoming vacant, *ii*) occupy another parking place not reserved for the delivery operations (i.e., parking in a lot destined to cars, or even double-parking; in any case, this choice produces a negative effect on the traffic), or *iii*) evaluate other possible alternatives (such as deferring the delivery to another day). In this study, we do not assume the availability of a support system allowing the driver to remotely know the actual utilization of a lay-by area. For the sake of exemplification, Figure 4 reports the results of the simulation of the arrival of four trucks at a lay-by with a single parking stall, reserved for commercial operations for 2 hours: when the stall is occupied, the other arriving trucks must wait. Beyond the reserved time window of two hours (120 minutes), the stall is occupied even though it may be available for other vehicle categories (e.g., cars).

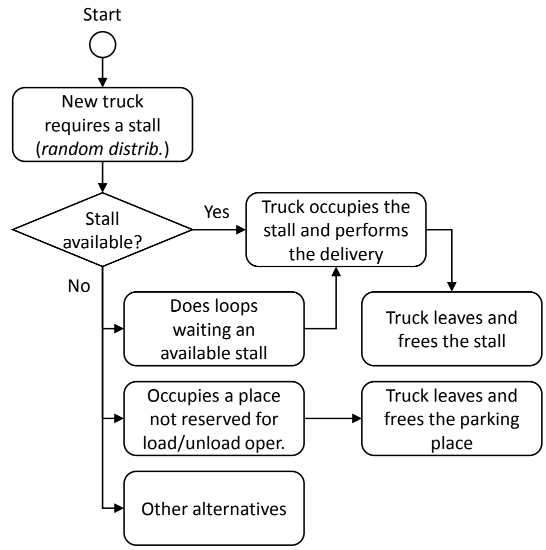

Fig. 3. Example of a general stall occupation process.

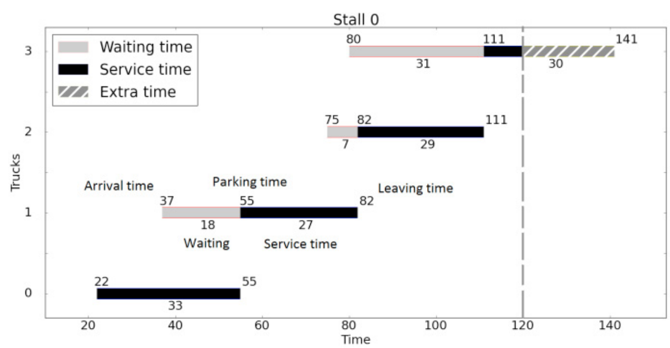

Fig. 4. Example of the occupation of a single stall from the simulation.

5. COMPUTATIONAL RESULTS: AN EXAMPLE

Due to the limited space available, we report here only the results related to the first option available when the best parking area is not available, that is to wait for an available stall in the best lay-by area. Let us consider one parking area *k=1* that serves $n_1 = 21$ delivery points. We assume a service window $T_1 = 180$ minutes, and an average loading/unloading time $t_1 = 30$ minutes as resulted from a local survey performed in the addressed area. We also expect that each delivery point receives on average $v_1 = 1$ truck per day. From (4), the minimum number of stalls to be placed in the lay-by area *1* is

$$S_1 = \left\lceil \frac{30 \cdot 21 \cdot 1}{180} \right\rceil = \lceil 3.5 \rceil = 4$$

Let us assume that the 21 trucks (i.e., an average of one per delivery point) arrive independently from each other; since the service time is 30 minutes on average, we assume that the last truck arrives no later than 150 minutes from the beginning of the time window T_1. We simulated the cases reported in Table 1; each case has been simulated 1,000 times. We used the uniform distribution for the sake of the example; however, any other distribution may be used, according to the available data. The average results for each case are reported in Table 2.

Table 1. Simulation cases

	Stalls	Number of trucks	Service Time (min.)	Arrival Interval (min.)
1	4	21	30	Uniform in [0, 150]
2	5	21	30	Uniform in [0, 150]
3	4	21	Uniform in [15, 35]	Uniform in [0, 150]
4	5	21	Uniform in [15, 35]	Uniform in [0, 150]
5	4	Int. random in [19, 23]	Uniform in [15, 35]	Uniform in [0, 150]
6	5	Int. random in [19, 23]	Uniform in [15, 35]	Uniform in [0, 150]

Table 2. Results summary

	Mean waiting (min.)	Max waiting (min.)	Std. dev. waiting (min.)	Time windows exceeded	Average exceeded time (min.)	Average stalls saturation
1	10.3	69	11.2	2165	26.585	83.8 %
2	3.2	47	5.8	598	4.883	69.4 %
3	4.9	53	7.4	583	4.851	72.3 %
4	1.5	32	3.7	258	1.250	58.1 %
5	5.2	62	7.7	728	6.573	72.3 %
6	1.6	38	3.9	230	1.116	58,0 %

6. DISCUSSION AND CONCLUSIONS

The mixed analytical-Monte Carlo simulation approach illustrated in this paper enables a thorough performance analysis of a design decision. In particular, the combination of an optimization model (using deterministic data) with a simulation model (dealing with random data) allows for a better understanding of the available alternatives. Analysing the data – summarized in Table 2 – it is possible to understand the potential impact of different options. For example, the design decision obtained using eq. (4) (i.e., four stalls) leads to fairly good performance even when the arrival times and the service times are stochastic. However, the performance degrades, especially in terms of waiting time and extra time when also the number of trucks is uncertain. Having these numbers about the different cases' performance, it is possible to evaluate the advantage and drawback of allocating one more stall in a given lay-by. As further development we foresee: *i*) the possibility to extend the considered area and to compare the actual performance of the as-is setting against the performance resulting from the model; *ii*) the possibility to include more information in the driver's stall occupation process, for example assuming the presence of an ICT support monitoring (as in the Area DUM project) and communicating the current occupation of each stall.

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