Evaluation of taxi services on airport terminal’s curbside for picking up passengers

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Abstract—Intermodal interfaces are extremely important for the transportation system as a whole. Therefore, designing and dimensioning airport terminals’ curbsides are major steps to improve passengers’ experience. Indeed, evaluating such design is a critical task that must be performed to point out the best solution. This paper reports our modeling, implementing, and evaluating two curbside scenarios: one as currently applied to the Portela Airport, in Lisbon, and another alternative as proposed by a Transport Consultancy Agency. Our contribution results in the creation of a broader methodology to evaluate various scenarios, in addition to determining the best scenario between the ones presented and discussed in this paper. Some preliminary experiments are carried out, whose results are presented and discussed so as to compare their efficiency. Finally, we draw some conclusions and point out ways in which this work can be further extended.

I. INTRODUCTION

Airports are important infrastructures of modern life and play a major role in the transportation of passengers with different purposes, such as tourism and businesses. Airport terminal curbsides are critical interfaces between standing vehicles, moving vehicles and pedestrians, and act as the capacity buffer between the road delivery system and the airport terminal building, being one of the main interfaces to access the terminal, either for passengers departing or for those arriving.

A correct design and dimensioning of airport terminals curbsides is a major step for achieving positive passenger experiences since long pedestrian paths, lack of information or long waiting time for transportation may cause passengers discomfort and bewilderment. Positive passenger experiences of airport use are crucial for improving their satisfaction and leveraging demand at airports.

In that concerning this type of multimodal interfaces, GlobalVia, a transport consultancy agency, during the 74th European Study Group with Industry Conference, in Aveiro, presented the challenge of measuring the efficiency of different curbside scenarios. So, we know that design and capacity of curbsides are essential to the successful performance of the airport infrastructure, in which case a question emerges: How to prove the efficiency of new curbside layout designs? Therefore, our aim is to create a broader methodology to model and evaluate curbside design alternatives in different scenarios.

In this work we focus on two scenarios as presented by GlobalVia, which are the Portela Airport current curbside layout and the one proposed by them. Furthermore, we intend to model the problem and replicate all proposed scenarios experimentally, so that we can assess and compare the two alternatives. More specifically, our goal is to evaluate scenarios performance by addressing several issues related to quality of service, in order to analyze the viability of the solution proposed. We want to implement a finer grained perspective based on behavioral models to observe some unusual situations, resulting from the social interactions of passengers, for instance.

Following this brief motivation of the topic, the remaining of this paper is organized as follows. In the next section, we discuss related works on queuing theory to understand how it can be used to simulate systems. In section II is presented a brief discussion focusing on pedestrian simulation. Problem and scenario description are then presented in the third section, finally followed by our methodological framework, experimental results, as well as conclusions and suggestions for future work.

II. RELATED WORKS

Queuing Theory is mainly seen as a branch of applied probability theory, which has applications to different fields such as communication networks [3], computer systems [1], machine plants [2], and traffic engineering [4]. The subject of queuing theory can be described as follows: consider a service center and a population of customers, which at some times enters the service center in order to obtain service. It is often the case that the service center can only serve a limited number of customers. If a new customer arrives and the service is not available or saturated, she enters a waiting line and waits until the service facility becomes available again [5].

On the other hand, the initial motivation for much research on pedestrian simulation was to provide better correlation between environment parameters, which is fundamental for
planning it. Further, this subject only started to gain relevance a few decades ago, being its initial knowledge basically gathered from empirical observations. Thus, with the intention of modeling and simulating behaviors two distinct level for pedestrian analysis are considered: the macroscopic level (models the flow of pedestrians using high-level mathematics often derived from fluid dynamics), and the microscopic level (treats individual entities separately at a high level of detail and interactions are usually governed by microscopic behaviors).

Thus, focusing on the microscopic level, which provides more flexibility in constructing passenger behaviors, the agent concept can be applied in pedestrian simulation due to its capacity to represent decision for various perceptions, reasoning, learning, and knowledge processing as well. In this context, the agent-based pedestrian simulation field encompasses modeling different types and level of behaviors, such as rule-based agents [6], social forces [7], and emotion agents [8]. Furthermore, there are a few tools to simulate pedestrian agents. Some of known platforms that use the agent paradigm are: STEPS [9], SimPed [10], Legion [11], Myriad II [12], and AnyLogic [13].

As for the specific problem being addressed in this work, an interesting master thesis [14] gives one example on how queue theory can be applied to curbside scenario. The work models the Portela Airport terminal and analyses the current scenario in a simple form, then proposes different policies and number of cars to use the curbside at a time. However the developed model considers micro-behaviors as simple functions.

Also, to the best of our knowledge, Queue Theory and Agent-based Simulation were never combined to extract the most possible realism of a waiting situation, in this case airport terminals curbside. As said before, the mix of these two approaches has great potential to add valuable information in modeling real systems.

III. PROBLEM STATEMENT AND SCENARIO DESCRIPTION

The common used solution for taxi service provision on passengers arrival curbside, currently implemented at Portela Airport, consists of a set of two parallel lanes next to the door of the airport terminal, with four stop areas that promote the passengers pick up, as shown in Figure 1, followed by taxis queuing and waiting for the departure of the taxis stopped in the stop areas.

This solution allows for a nearly independent functioning of the two groups of (two) taxis at the stop areas, one group in each of the two lanes. However, the service of taxis in the same lane is strongly linked, with a blocking effect occurring in two directions: (a) the presence of a taxi in the front row in a given lane prevents all taxi on the back row in the same lane from departing even if it has completed the picking up of a passenger group, and (b) the presence of a taxi in the back row in a given lane prevents all taxi at the top of the queue in the same lane from moving to the stop area in the front row of the same lane when this stop area is free.

With the increase of air traffic observed over the past few decades, we realize the formation of large queues of customers waiting for taxi during peak hours. Thus, a progressive accumulation of passengers at Portela Airport waiting for taxi service over the second half-hour of a one-hour period is very likely and frequently observed. The formation of long queues is caused by the taxi demand exceeding the taxi departure capacity at the taxi service provision during peak hours. The taxi service provision has not kept pace with the increase in taxi demand over recent years, and such demand service capacity mismatch results in significant undesirable customer delays. As a consequence, in order to mitigate these delays, more efficient taxi service provision designs, to be implemented at least in peak traffic hours, are welcome.

With this very scenario in mind and as an attempt at improving it, Globalvia proposed a new design for taxi service provision. The proposed solution, illustrated in Figure 2 consists of a “spin” design for taxis at arrival terminals (and another one at departure with an identical geometry but for private cars) with a lane parallel to traffic routes from which taxis approach the stopping area. The parking positions are arranged at 45 degrees with respect to the road, aligned parallel to each other.

Thus, the vehicle coming from the adjacent track, either being taxis (at airport arrivals) or private vehicles (at airport departures), after stopping, follow a route that is dedicated exclusively to them. This creates a traffic flow independent from other cars, thus minimizing all points of conflict between vehicles. Nonetheless, the parallel design of the spots for taxi stops has the drawback of customers being no longer able to wait “in front” of the taxistand. In fact, customers will be informed of the number of the taxistand they should go to for boarding a taxi, and will experience an additional walking time from the queue to that taxi stop.
A methodological framework was devised, covering aspects as modeling and simulation. In this section, we describe how our problem was model, which abstractions were used to achieve it. Also, complexities and constraints in this problem were identified. From that a simplified model of an abstraction of the application domain was created without losing key aspects, such as certain degrees of realism. The manner that this model was translated for use in known simulators is discussed on the following subsections.

A. Modelling

The used strategy to model the problem was to abstract similarities between both scenarios and, by observing Figure 3, we can realize this task more intuitively. The achieved abstraction has three parts: the waiting queue, a mode to route passengers, and taxis. Thus, the dynamic interaction of these parts can be described as:

- the passenger arrives at the waiting queue and waits for his/her turn. When it is his/her turn, they are directed by a generic router (e.g. a display or even passengers self-organization behavior), and will walk to the respective taxi. Further, arriving there they must load theirs luggage, enter in the taxi which has to leave so next taxi can occupy its place.

Therefore, as the goal is to evaluate and compare scenarios performance, the passenger’s total waiting time have to be measured. This time was divided in four components:

- \( t_{\text{waiting}} \) - corresponds to the time that the passenger waits in the queue until a taxi is designated;
- \( t_{\text{walking}} \) - is the time a group of passengers spends from the waiting place until taxi’s position. This time is dependent on the building map and person type, respecting the last a normal distribution;
- \( t_{\text{loading}} \) - indicates the spent time to place the luggage inside the taxi, and also that all group get inside the taxi. Depends on the quantity of luggage and number of people;
- \( t_{\text{leaving}} \) - this is the time spent during taxi’s departure and other taxi’s arrival in one curbside. It has a distribution dependent on the ability level of the taxi driver and the current traffic situation.

and being

\[
T_{\text{TOTAL}} = t_{\text{waiting}} + t_{\text{walking}} + t_{\text{loading}} + t_{\text{leaving}}
\]  

Finally, with \( T_{\text{TOTAL}} \) we can demonstrate the existence or inexistence of any improvement on time spent in the curbside, specifically on the Portela Airport scenario and the scenario proposed by GlobalVia. Thus, after modeling the problem we need to bring this representation onto a real implementation environment.

In order to implement the model described above, we need to specify how to simulate and extract desired information for each part and then couple them together. Taking into account the modeling approach adopted in this work, the \( t_{\text{waiting}} \) will be found using the SIMUL8 Simulator. In \( t_{\text{walking}} \), we had two paths: math analysis to discover the maximum time for walking and how crowded situations can interfere on it. Then, \( t_{\text{loading}} \) and \( t_{\text{leaving}} \) were extracted from real measurements from previous study [14]. Excel will sum the factors and plot out graphs of \( T_{\text{TOTAL}} \).

B. Simulating Queues

For the construction of this model, SIMUL8 [15] software was chosen. SIMUL8 is a computer package for Discrete Event Simulation from SIMUL8 Corporation. It is frequently used in the modeling of industrial processes or services such as hospitals, repair shops, gas stations, etc., focusing on queuing systems. This choice was based on two main reasons, the software explicitly considers randomness and variability, also it is user-friendly and visually simple, focusing on the main elements of a queuing system.

Based on the building block types, their possible attributes and on the relationships between them, the basic system configuration was iteratively built and tested until stabilizing on a final setup (Figure 4). In order to reach this last setup, several conceptual questions were asked about the way to better model the arrival and service of passengers, especially the intention to model groups.

According to this study, customers arrive to the taxistand rank according to a Poisson process with the (exponentially distributed) customer interarrival times having mean \( \lambda_G \) seconds, where \( \lambda_G \approx 0.078 \). Further, the \( t_{\text{loading}} \) and \( t_{\text{leaving}} \) were couple together as individual customer service time (or taxi service time), which is log-normal distributed with \( m = 75.46 s \) and \( t = 0.183 \) for all scenarios.

Modeling groups has a relevant impact on the system, either because groups tend to spend more time in coordinating and boarding a taxi or a set of taxis or because they also condition the number of taxis that are required. The characterization of the passenger group size was done based on the Portela Airport study-case provided in [14].

The taxis dependency in the same lane, for current scenario cited in the section IV, was modeled in SIMUL8 in a virtual form using VisualLogic language. Briefly, work items from Work Centers Taxi that are not in the first line can just be released if do not exit a work in all Work Centers in front of it, or when they release their work items. Therefore, simulation
dynamic is: pedestrians groups are created in the Entry Point, and then each individual of the group is created and labeled. Pedestrians are divided and go to the queue, which routes passengers for taxis. Taxis have a work time with Lognormal distribution and all pedestrian are counted in the Exit Point.

The simulation duration was set to 3600 seconds (1 hour), approximately equivalent to the 3566 second-period (59 minutes and 26 seconds) which the analysis on the collected data was based on, basically representing a whole peak-hour of operation. Walking distances and times were set to zero, because these are going to be treated by other simulation. Also, the Random Sampling methods was used to every run random sampling yields give different set of result.

C. Finer Grained Simulation

In order to improve our model, a finer simulation was inserted. The goal of this component is find if the walking time to reach the taxi is significant in the scenario analysis. Also, which components influence this time, for instance, number of cars, their disposition, and the building design. Thus, unusual situations are going to be analyzed in a qualitative form to define its influence level.

Therefore, to calculate $t_{\text{walking}}$ we decide to use a mathematical method, because it proved to be enough to model this factor. So, walking time was considered for the worst case, i.e., for the biggest distance which the passenger has to walk. This distance varies with the number of cars and, in Figure 5 we can see the maximum path for 4 taxis scenarios, being all values taken from the floorplan.

After initial experiments, it was observed that the queue length could induce a crowd situation in the path to reach taxis. Thus, we realized that it was necessary some test with these situations, because they could interfere with the system performance, increasing $t_{\text{walking}}$. Therewith, the ModP simulator was used to do qualitative analyses, however none of these results can be added to the final result due to the lack of quantitative measurements.

Focusing on ModP, it was devised and has been developed within the LIACC Lab, University of Porto, since 2009 [16]. This simulator was developed as a multi-agent system from scratch, implemented in C++ with the Qt framework [17] for interfaces, the OpenSteer [18] library for implementing steering behaviors and the OpenGl[19] framework for the 3D viewer. Further, it has four main modules, namely a graphic editing interface, a 3D viewer, a simulation engine and a data analyzer.

The passage to a ModP model was made respecting real proportions. The sidewalk’s limits and crosswalk were set as walls, because we assume that pedestrians, in ideal situations, always will walk using them. Further, taxis are rooms which certain type of agents was to enter. Exist two types of agent in this simulation: the passenger that has the goal to enter in the taxi (represented by room), and the crowd which agglomerate in determined points to complicate passenger agents to pass. The followed path by the passenger is the demarcated in Figure 5, also experiments proceeding will be described in the next section.

V. EXPERIMENTAL RESULTS AND DISCUSSION

With the system modeled and implemented in the respective simulators, we can perform all needed tests. So, five results were extracted, such as taxi stands using rate, comparison between queue length and queuing time for all scenarios, walking time, qualitative analysis of crowd situations and, finally, final results with total waiting time for each scenario. To simplify results understanding, we determine a label for experimented scenarios, as shown in Table I.

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>Current with 4 taxis</td>
</tr>
<tr>
<td>Scenario II</td>
<td>Proposed with 4 taxis</td>
</tr>
<tr>
<td>Scenario III</td>
<td>Current with 4 taxis</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>Proposed with 4 taxis</td>
</tr>
<tr>
<td>Scenario V</td>
<td>Current with 4 taxis</td>
</tr>
<tr>
<td>Scenario VI</td>
<td>Proposed with 4 taxis</td>
</tr>
</tbody>
</table>
In the Table II are shown taxis stand time percentages for working, waiting, and blocked. Thus, two interesting analysis can be taken from it. First, it can be seen that for the current scenario, in average, 33.4% of the using rate taxis are blocked (except for the ones in front of the line that are always working). This average was presented in all scenarios. Nevertheless, for the parallel scenario, all taxis work with full capacity, because there is no dependency between them.

### TABLE II. TAXIS STAND TIME PERCENTAGE FOR ALL SCENARIOS

<table>
<thead>
<tr>
<th>Type</th>
<th>Working</th>
<th>Waiting</th>
<th>Blocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>65.90</td>
<td>9.13</td>
<td>25.97</td>
</tr>
<tr>
<td>Scenario II</td>
<td>66.81</td>
<td>9.41</td>
<td>24.78</td>
</tr>
<tr>
<td>Scenario III</td>
<td>99.74</td>
<td>0.00</td>
<td>0.26</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>96.49</td>
<td>0.00</td>
<td>3.51</td>
</tr>
<tr>
<td>Scenario V</td>
<td>33.00</td>
<td>0.00</td>
<td>67.00</td>
</tr>
<tr>
<td>Scenario VI</td>
<td>3.00</td>
<td>0.00</td>
<td>97.00</td>
</tr>
</tbody>
</table>

We can observe from Figure 7 average and maximum queue length and, for all scenarios, maximum length is almost the double of average value. However, the difference between maximum and average for current scenarios are bigger than the difference between averages. Also, maximum queue length help us to measure the system’s critical point when the service has to be as efficient as possible, so the passenger flow be the highest, increasing the quality of service. Thus, 213 people are the maximum quantity in the queue.

### TABLE III. LABELS OF THE STUDIED SCENARIOS

<table>
<thead>
<tr>
<th>Label</th>
<th>$t_{walking}$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>20.16</td>
</tr>
<tr>
<td>Scenario II</td>
<td>23.47</td>
</tr>
<tr>
<td>Scenario III</td>
<td>23.76</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>26.52</td>
</tr>
<tr>
<td>Scenario V</td>
<td>27.36</td>
</tr>
<tr>
<td>Scenario VI</td>
<td>29.58</td>
</tr>
</tbody>
</table>

Furthermore, pedestrians’ interactions were experimented using a simple method. We set four scenarios: without, little, medium, and big crowd. In Figure 9, snapshots of performed simulation were taken (none and medium crowd), observing the accumulation point and the path (represented by blue points). Thus, current scenario, with a little crowd, presents some problems in passenger flow and, for medium, there is none flux of them. Additionally, for proposed scenario, with medium and big crowd none flux were seen. So, both scenarios have a bad performance in this experiment, however improvements in the simulation realism must be done.

In the following graph, final results are presented, observing the difference in waiting for each scenario, being them grouped in respect of number of taxis. The proposed scenario shows to be always more efficient, as expected due to its parallel nature. Nonetheless, it becomes evident that the performance variation is extremely connected with the number of vehicles, i.e., for the 4-taxi scenario the variation is 15 seconds, and for the 8-taxi scenario, it is noticed increases in the order of 2 minutes and 48 seconds.

Therefore, the average queuing time for current and proposed scenarios are, respectively: 6.5 min and 6.15 min for 4 taxis, 5.58 min and 3.66 min for 6 taxis, and 3.9 min and 1.02 min for 8 taxis. Thus, the proposed scenario offers an

![Figure 7. Average and Maximum queue length for each scenario](image)

![Figure 8. Average and Maximum queuing time for each scenario](image)

Based on the model from previous section and in the person average walking time of 5km/h, values shown in Table III were calculated. So, the distance increases proportionally as the number of cars, also to the proposed scenario, due to cars’ disposition and building design, the $t_{walking}$ is always higher. Finally, for scenarios with lower queuing time, the walking time can interfere with the final results, validating its analysis in this study.

![Figure 8](image)
improvement in the curbside’s quality of service. Furthermore, it is also important to remember that in these analyses we do not take into consideration any factors related to costs and the necessary space to construct each design layout.

VI. CONCLUSIONS AND FUTURE WORK

Intermodal interfaces are extremely important for the transportation system as a whole. Therefore, airport terminals curbsides’ design and dimensioning are major steps to improve passengers’ experience. However, evaluating their designs has not been a major concern of the scientific community.

A new approach was presented to model curbside scenarios aiming to evaluate their performance. Furthermore, by using this method we show all steps to implement the current scenario as well as the one proposed by GlobalVia in a simulation environment. We determined parameters to compare them and carried out some preliminary experiments. Experimental results show that for a small number of taxis two scenarios present almost the same result, with advantages by the GlobalVia proposal. On the contrary, with high number of taxis the proposed scenario is much better then the current one.

There is a sequence of tasks that could follow up the present work. We point out some of them. First, we need to perform measures for $t_{	ext{loading}}$ and $t_{	ext{saving}}$, for different airports, and try to determine a general function for it. Alternatively, a method to easily infer these times for various scenarios can be devised as well. Also, we intend to improve the ModP environment so as to present quantitative results regarding pedestrian interactions while walking, i.e., we need to use the ModP simulator to determine $t_{\text{walking}}$ more realistically and not only on the basis of maximum values. Simulating different types of crowd configuration, such as populations that include children and elderly is a very next step to determine their interference in the system performance.

REFERENCES


