Multi-Resolution Simulation of Taxi Services on Airport Terminal’s Curbside

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Abstract—Inter-modal interfaces are extremely important for the transportation system as a whole. Therefore, designing and dimensioning airport terminals’ curbsides are a major step 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 on our modelling, implementation, and evaluation of two curbside scenarios: one as currently applied to the Portela Airport, in Lisbon, and another alternative as proposed by a Transport Consultancy Agency. The contributions are to create a broader methodology to evaluate various scenarios as well as to combine different granularities of analysis in order to leverage a multi-resolution simulation where, under more realistic circumstances, the best scenario can be pointed out. Some preliminary experiments are carried out, whose results are presented and discussed so as to compare their efficiency. Finally, we draw some conclusions and identify 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. Additionally, 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. Their correct design and dimensioning is a crucial 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.

Regarding this type of multi-modal 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 curb-side scenarios. This gives rise to a question: how to prove the efficiency of new curbside layout designs and thus compare performance with the current one? In Passos & Rossetti [18] a macroscopic simulation approach was used to tackle the problem quantitatively. The authors used as well a microscopic pedestrian model to provide a qualitative evaluation only of the proposed layouts. This paper aims to answer this question by creating a broader methodology to model and evaluate curbside design alternatives in different scenarios. The present work is to be considered continuation of previous research [18].

We focus on two scenarios presented by GlobalVia, which are the Portela Airport current curbside layout and the one proposed by them. Furthermore, we are going to model the problem taking into account the specificities in respect to queue formation and pedestrian features. This work aims to evaluate scenarios’ performance by addressing several issues related to the quality of taxi service in order to analyse the viability of the solution proposed.

To couple all levels of abstractions demanded to these particular scenarios, a multi-resolution approach is used aiming at the analysis of this particular problem. It addresses two levels of resolution: first, a macroscopic level where a queue-based model estimates the waiting time; and then an agent-based microscopic model simulates walking behaviours of passengers. As multi-resolution tries to merge different perspectives of the same problem, the central challenge of this research is to define appropriate boundaries for the macro and micro simulations so there is no over-effort. Analyse results is also demanding because they must be taken as a whole and thus correspondences should be established.

Following this brief motivation of the topic, the remaining of this paper is organized as follows. The next section discusses the related works in all main areas involved in this paper, such as queueing theory and pedestrian simulation. Section III presents a discussion on the problem statement and, further, deeply describes all scenarios. Moreover, in Section IV, a methodological framework is proposed to achieve our goal; followed by experimental results and their discussion (Section V). At last, some final conclusions and possible future works are drawn.

II. RELATED WORK

Often modellers and analysts need to examine the throughput performance of the real system or of the subsystems of it using different perspectives and metrics for its appraisal. Thus modellers need to use different level of abstraction for representing the reality according to the necessity of their study and purposes. The existing modelling approaches that can be found in the simulation literature can be roughly divided into two main categories: macroscopic and microscopic models. The two classes of approaches emphasize on
different detail levels of the target system and data aggregation, leading thus to different resolution models. Abstractions at diverse levels of resolution have their own strengths and weaknesses and thus no model can be completely replaced by another. Macroscopic models fail to apprehend the individual behaviour of vehicles or pedestrians, as it can be the detailed situation of traffic network in an intersection, while microscopic models cannot capture global performance.

Such a multi-resolution approach is a very often practice in traffic and pedestrian simulation [1], [3]. In Ma et al. [4] is proposed a new classification of traffic model according to the representation scale and the behavioural law. The goal of this paper is not to discuss the theme extensively; for a deeper review, the reader is invited to consult the references [1], [2], [5]. In Xiong et al. [7] a hybrid modelling approach for crowd simulation is proposed, aiming to exploit advantages from both macroscopic and microscopic models. Authors conclude that combined hybrid models can offer significant advantages over traditional approaches as the simulation results are improved in efficiency by means of the macroscopic model and leveraged in terms of accuracy of a fine-grained simulation result by adopting the microscopic model.

Thus, focusing on the microscopic level, which provides more flexibility in constructing passenger behaviours, 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 modelling different types and levels of behaviour, such as rule-based agents [8], social forces [9], and emotional agents [10]. For example, [11] presents a prototype of a pedestrian model using JACK Sim and evaluated the prototype. The model prototype is built of pedestrians moving around a network and considered as a directed graph using two types of pedestrian with and without prior knowledge of the routes through the environment. [12] presents an agent-based navigation approach to control the movements of passengers in virtual environments that mimics crowd dynamics in transfer hubs. [13] discusses the potential of crowd simulation tools in architecture and urban planning.

As for the specific problem being addressed in this work, [15] gives one example of how queue models 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-behaviours as simple functions. From the literature review, it is possible to state that to the best of our knowledge queue-based and agent-based simulations were not as yet combined to extract the most possible realism of a waiting situation, in this case airport terminals curbside. As said before, the cooperation of these two approaches has great potential to add valuable information to modelling real systems as it combines the vast experience in diverse domains of the first with the inception of human-like aspects provided by the second.

III. SCENARIOS DESCRIPTION

This paper deals with two scenarios, both deeply explained hereafter. A common 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 exit 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 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 taxis (in the same lane) on the back row from departing even if they have completed the picking up of a passenger group, and (b) the presence of a taxi in the back row in a given lane prevents every taxis 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.

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. In order to mitigate these delays, more efficient taxi service provision designs are welcome to be implemented at least in peak traffic hours.

With this 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-like” design for taxis at arrival terminals (and another 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 be-

![Fig. 1. Portela Airport current scenario](image-url)
tween 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.

IV. METHODOLOGICAL FRAMEWORK

This section describes how the problem was modelled, as well as which abstractions were used to achieve it. Also, complexities and constraints inherent to this problem were identified. From that, a simplified abstract model of the application domain was created while realism plays a role in it. The strategy devised to translate the model into actual simulation is discussed in the following subsections.

A. Overall Modelling

Both scenarios were generalized regarding their similarities and, by observing Figure 3, they are more intuitively understood. 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 behaviour), 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 into 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 luggages 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 the 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

$$t_{\text{TOTAL}} = t_{\text{waiting}} + t_{\text{walking}} + t_{\text{loading}} + t_{\text{leaving}}$$  \hspace{1cm} (1)

Finally, with $t_{\text{TOTAL}}$, it is possible to demonstrate the improvement or not on time spent in curbside, specifically on both Portela Airport and GlobalVia scenarios. Furthermore, the $t_{\text{waiting}}$ will be found using the SIMUL8 Simulator [16]. An agent-based perspective had been followed for estimation of $t_{\text{walking}}$ with both single or grouped passengers. Finally, $t_{\text{loading}}$ and $t_{\text{leaving}}$ were provided by real measurements from previous study [15].

B. Simulating Queues

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

Modelling groups has a relevant impact on the system, either because groups tend to take more time when 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 case study provided in [10]. In order to model this aspect in SIMUL8 environment, it was created a batch size label initialised with a value given by a certain distribution. The first work center, entitled Identify Group, creates a unique ID number for each work item (still a group, at this stage), in order to be able to distinguish this group and every future subdivision/multiplication of it, in terms of group members. The second work center, entitled Disaggregate, has the function of disaggregating the group into a number of passengers that equals the Batch size label value, each with the ID of the corresponding original group.

Briefly, work items from the Taxi Work Centers hold all assumptions from the proposed model and, therefore, the simulation dynamic is as follows: pedestrians groups are created in the Entry Point, then each individual of the group is created and labelled; pedestrians are divided and go to the queue, which routes passengers for taxis; further, taxis have a
working 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) on which the analysis on the collected data was based, 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 method was used so that random sampling yields different set of results for every simulation run.

C. Finer Grained Simulation

In order to improve our model a fine-grained representation of the system is proposed as complementary to the macroscopic model discussed above. The purpose of this component is to examine whether the necessary walking time to reach a taxi is important when analysing the scenario’s configuration. Examining this perspective of the system can capture the interactions among different entities or artefacts used to represent the reality. Thus, unusual situations are going to be analysed in a quantitative (but also qualitative) form to define its influence level.

To simulate the taxi services operations and the passengers’ movement, a microscopic model of the airport terminal’s curbside follows the agent-based paradigm. The agent-based model represents the real order picking entities and simulates the customer service indicators. For this work, it has been used the NetLogo modelling framework [17] to rapidly prototype simple, yet realistic, “what-if” scenarios and analyse the system performance under different real setups.

The proposed approach (Figure 4) assumes that the scenario has two types of agents: passengers (persons), and taxis. The first can be characterized as crowd, that is, persons who just move around the airport’s terminal; or passengers whose goal is entering in a taxi. The $t_{\text{walking}}$ of passengers (that the model intends to evaluate) might be affected when interacting with the crowd.

Moreover, to build the model of the airport terminal’s curbside picking system, a number of assumptions were made in order to abstract the real case maintaining, however, a degree of validity. The scenario is represented as a discrete grid-based environment and, thus, it is divided in 200 per 100 cells where each of them is equivalent to an area of 0.25$m^2$ in real-world proportions. According to [14], the space occupied by a person is approximately 0.2$m^2$, then only one person can be in a cell. For granularity purposes, each passenger has an associated age that affects its speed where a young, adult and elder persons have walking velocities of 1 m/s, 1.4 m/s and 0.8 m/s, respectively [5]. Regarding the moving behaviour, the passengers are modelled to mimic the behavior of a person following indicative signs. This approach is pretty much intuitive and reflects how people look for guidance in public places when they are not much familiar with the environment.

Before the agent actually starts to walk three decisions must be made by the system: the amount of people travelling together, when it (or they) will appears in the simulation and what is its (or the group) speed, determined by the age as aforementioned. The first and the second are driven by the same probabilistic distributions used in the macroscopic simulation. The third concerns the distribution of probabilities as follows: 50% to be an adult, 25% to be a young, 25% to be a elder. Furthermore, when a heterogeneous group is created the group will assume the minimum velocity of its members. The velocity of a group can also be affected by a give factor such as the size of a group (large group tend to walk slower than small groups).

The passengers are assumed to be in a “waiting” status in the airport internal premises and to each group of passengers is assigned a (virtual) ticket. When a resource (taxi) is free, the corresponding group exits the airport terminal and heads towards the curbside picking point. This assignment strategy is realistic as it has been adopted in different airport terminals. Each single passenger chooses a trajectory based on his perception of the virtual signs position and the crowd’s interaction. It is also considered that always exist availability of taxis and the capacity of them can satisfy passengers’ demand.

V. EXPERIMENTAL RESULTS AND DISCUSSION

With the system modelled 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 follows: Scenario I (Current with 4 taxis), Scenario II (Proposed with 4 taxis), Scenario III (Current with 6 taxis), Scenario IV (Proposed with 6 taxis), Scenario V (Current with 8 taxis), and Scenario VI (Proposed with 8 taxis).

Table I shows the time percentage at taxis stands for each of the states: 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.

We can observe in Figure 5 that the maximum value of queue length almost doubles the average value of it for all scenarios. However, the difference between maximum and average values of the queue length for the current scenario is greater than the differences between maximum and average values for the proposed ones. Also, maximum queue length helps 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.

Average and maximum queuing time are presented (Figure 6). This result is the main component of the total waiting time and we can observe that for scenarios I and II the performance difference is just 15 seconds. Nevertheless this difference grows for 2 minutes for scenarios III and IV, keeping in V and VI with lower absolute values. Thus, for maximum waiting time it can be seen that all values are much higher, being in scenarios I, II and III all times higher than 23 minutes, impracticable in real situations. Also, 3 minutes to wait in scenario VI is acceptable depending on expended resources.

In regard to the $t_{walking}$, it was performed ten runs to each scenario and their average curve can be seen in Figure 7. Each curve stabilises in a certain value and, inside each scenario, this value is not the same yet they are in a ten-seconds windows. This was expected because all experiments make usage of the same probabilistic distribution of groups velocity. Additionally, the stabilisation time for current and proposed scenarios are different which is correlated with the agents behaviour. In other words, for the current scenario, the layout is much more linear and then agents’ paths are similar; this is different from what happens in the proposed scenario, where agents have a more stratified path and then a broader variety of choices. Finally, for scenarios with lower queuing time, the walking time can interfere with the final results, validating its analysis in this study.

As a final result, Figure 8 portrays the average time spent by a passenger from joining the queue up to leaving with the taxis. The results were grouped according to the number of taxis. Thus, the GlobalVia scenario always performs more efficiently than the current one, which is expected from its parallel nature, yet it should be proven. Nonetheless, it becomes evident that the performance variation is extremely connected to the number of vehicles, that is, for the 4-taxi scenario the variation is 15 seconds and, for the 8-taxi scenario, it increases in the order of 2 minutes and 48 seconds.

To quantify the performance difference between both is computed, respectively: the average total time for current

![Fig. 5. Average and Maximum queue length for each scenario](image)

![Fig. 6. Average and Maximum queuing time for each scenario](image)

![Fig. 7. Average walking time for both scenarios](image)
and proposed scenarios, respectively: 9 and 8.27 minutes for 4 taxis, 7.92 and 5.73 minutes for 6 taxis, and 6.23 and 3.09 minutes for 8 taxis. As for the final conclusion regarding which scenario performs better it was quantitatively proven that the scenario proposed by GlobalVia offers an improvement in the curbside’s quality of service. Noteworthy is that this analysis did not consider factors related to cost and the necessary space to construct each layout.

VI. CONCLUSIONS AND FUTURE WORK

Intermodal interfaces are extremely important for the transportation system as a whole and, therefore, the task of designing and dimensioning them is a crucial steps towards the improvement of passengers’ experience. Airport terminal curbsides’ are included in this category as they represent the connection between aviation and land transport, specifically taxis for the case discussed. A general purpose methodology were proposed to model and evaluate different arrangements of taxis in the aforementioned curbsides. It was devised aiming to compare the current taxis arrangement of Portela Airport, in Lisbon, and the solution proposed by GlobalVia.

In order to quantify asset performance, a multi-resolution analysis was used with a macro and microscopic alignment. The first employed a simulation of queues to determine the time that a passenger usually will wait for a taxi in both scenarios (and variances of these). The latter applied agent-based simulation where agents represent passengers walking to an available taxi; such a finer grained perspective gave a more realistic value for the time spent walking to a taxi. After some experiments, it was possible to draw some conclusions about performance in all scenarios. Results shown that, for a small number of taxis, both scenarios presented almost the same result with slight advantage of GlobalVia’s proposal. On the other hand, with higher number of taxis, the proposed scenario is much better than the current one.

This work, however, can be improved so more realistic situations and behaviours help to analyse the response of airport terminal curbsides under certain conditions. A first step should include performing measures at different airports for $t_{loading}$ and $t_{leaving}$ taking into account factors such as: amount of suitcases, size of the group and the taxi, and so forth. Also, a standard method to measure these times would facilitate correlations among gathered data. The NetLogo model will be improved to encompass all aspects of the model, not only $t_{walking}$, and thus compare a multi-resolution with a total microscopic simulation. From a scientific point of view, this is an important case study to clarify strengths and weakness of both paradigms. At last, the short-term improvement for the present work is two-fold: simulate more realistic composition of passenger group, for instance, vacations seasons may increase children and elderly percentage; and interaction of passengers and taxis with the crowd and traffic that could affect $t_{walking}$ and $t_{leaving}$.

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