Simulation model for assessing passengers' dwelling patterns: case study of Lisbon T2

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Abstract

The present Master dissertation aimed to evaluate and eventually propose, through a simulation model, some alternatives regarding the commercial layout of the terminal T2 in Lisbon International Airport. In order to achieve these objectives, a literature review was made before anything else, in order to better understand what approaches previous researchers had used and what main conclusions had been reached regarding pedestrian modelling, air passenger processes, discrete choice procedures, airport retailing and shopping behaviour in general.

Once the most determining individual characteristics for discretionary purposes inside an airport were noted and the most commonly used software tools were highlighted, a generic simulation model was developed in AnyLogic software in order to represent the passenger arrival distribution from security to the restricted area of the terminal, the way of functioning for their discrete choice process among a finite set of discretionary activities and, finally, the boarding stage.

That general model was then applied to a specific case study (Lisbon T2) and the current situation was analysed through some specific performance indicators defined by the author. These parameters' values revealed that the commercial layout of the terminal could be improved both from the passengers' and the managing entities' perspectives, so six different alternatives were proposed and simulated. Four of these proved themselves as leading to better results overall, being the best one a combination of three different modifications in the relative positioning between different facilities inside the terminal layout.

Keywords

Airport, simulation, pedestrian modelling, decision-making, commercial layout, Lisbon airport.

Introduction

Air transport has been considered, statistically speaking, the fastest and safest mean of transport of all. Nowadays, airports play a major role in the transportation of both people and goods all over the world. This role has been growing throughout the years and is becoming even more important in Europe than it used to, thanks to the increasing number of low-cost companies. In the city of Lisbon, Portugal, in particular, a globally positive trend has been being observed in terms of passenger flows, especially since 2009 (ANA, 2014).

Furthermore, due to the market liberalisation and its consequences, airports have been putting a considerable amount of effort on non-aeronautical revenues, leading to a strong growth in airport retailing (Zenglein & Jürgen, 2007), namely because such sectors typically lead to higher profit margins than the merely aeronautical one (De Neufville & Amedeo, 2003, cited in Zenglein & Jürgen, 2007). This tendency has been being observed in the last decade more than ever before, in several places of the globe. In the USA, for example, non-aeronautical revenues accounted for 44.8 % of the total, in the year of 2013 (ACI, 2013).

Therefore, the quality of the services that are offered inside the airports is becoming more and more important. Being passengers the most important entities involved in an airport, their personal experiences and opinions are extremely relevant in order to measure that service quality, which airport managers aim to enhance as much as they can. Depending on several aspects (economic, technologic or safety-related), managerial measures are taken and passenger flows inside terminals need to adapt and change. Since building new spaces ends up becoming impractical at some point, both for spatial and economic reasons, these improvements should take advantage of what has already been built, whenever possible.

According to the annual report of 2014 by ANA (2014, p. 15), one of the main objectives for the management entities of the Portuguese airports for 2015 is to «ensure that the shopping area layout and offer continues to best serve [their] passengers' interests. [They] expect that, over the next three years, this effort will result in significant growth in the commercial areas in general and in [their] retail offer in particular». Therefore, and keeping in mind that making physical experiments with the spatial layout and waiting for people to react to it before drawing important conclusions would be way too consuming both in terms of time and money, the creation of a simulation model seems like an interesting way of approaching the matter.

Some research has been done throughout the years in order to try to improve airport terminals all around the world. Several of these works focus on the mandatory activities passengers have to undertake (such as check-in, security, immigration and boarding), which is not sufficient nor realistic when the scope is to improve the passengers' experience as a whole; other scientific documents focus on commercial spaces, either inside or outside airports; but no work was found in which a model for people's shopping behaviours was created and applied, through a simulation process, to the context of a retail space inside an airport terminal with the aim of finding a better relative position of the different facilities. The main objective of this work is to develop such a model, so that the case study (Lisbon T2) can be assessed as it is now and the author is able to propose alternative layouts, both from an average passenger's and a managing entity's points of view.

One of the main challenges for such a model consists of creating a logical representation of the pedestrians' discretionary behaviour during their individual dwell times, harmonised with their obligations as air passengers after security. Since they are humans, they tend to behave in a rational way based on their perception of the environment they are in. When inside an airport terminal, the way they find their paths is an autonomous process, based on their cognition and basic psychological traits. This rationality, however, is not too evident from someone else's point of view, making it more defying to model it through mathematic variables and formulas.

Some authors in the past (Livingstone et al., 2012; Ma, 2013) have distinguished two types of activities for passengers when inside an airport: processing and discretionary. The first category stands for activities that need to be done in order for passengers to get to boarding; the latter type of activities regards the ones undertaken by passengers during non-processing times, including retailing and others. Authors, overall, have agreed with each other and have reached similar conclusions. In terms of passenger segmentation, the distinction between groups is usually similar. For example, Geuens et al. (2004) and Chung et al. (2013) had people divided into three types of shoppers in common: mood shoppers, apathetic/indifferent shoppers and shopping lovers. Chung et al. (2013) added traditional shoppers to that list as well. In terms of commercial space, mood shoppers are the ones who are most sensible to atmosphere-related and experiential factors and would prefer to have centralised stores, while shopping lovers would rather have fewer but bigger shops, closer to the departure gates. Hampson & McGoldrick (2013), however, defined a different shopper typology for a context of recession: the maximum adaptors, the caring thrifties, the minimum changers and the eco-crunchers. The general tendency for shoppers in such context is to become more knowledgeable and worried about the value of money than in "normal" situations.

Also, the relevant variables that researchers have considered as being explanatory are often the same (even though some authors go further into detail than others). The variables that commonly appear as possibly relevant for shopping behaviours are gender (Freathy & O'Connell, 2012; Geuens et al., 2004; Ma, 2013; Perng et al., 2010; Wesley et al., 2006), age (Geuens et al., 2004; Ma, 2013; Perng et al., 2010; Wesley et al., 2006), nationality/culture (Geuens et al., 2004; Ma, 2013; Van Oel & Van den Berkhof, 2013), income (Perng et al., 2010; Wesley et al., 2006), group composition (Freathy & O'Connell, 2012; Livingstone et al., 2012; Ma, 2013; Perng et al., 2010), flight/trip characteristics (Freathy & O'Connell, 2012; Ma, 2013; Perng et al., 2010), travel frequency/capacity (Denver International Airport, 2009; Freathy & O'Connell, 2012; Geuens et al., 2004; Lin & Chen, 2013; Lu, 2014; Ma, 2013) and previous purchase behaviour inside an airport (Geuens et al., 2004; Perng et al., 2010). Wesley et al. (2006) highlighted the pre-planned expenditure as well as a very relevant factor on the customers' satisfaction and activities in a commercial space.

Several researchers have made a distinction between pre-planned and impulse shopping and focused on that difference (Crawford & Melewar, 2003; Freathy & O'Connell, 2012; Lin & Chen, 2013; Lu, 2014). Perng et al. (2010) also concluded, in their work, that passengers who spent money at cafés generally did so on impulse. It would be interesting, from an economic point of view, to maximise impulse shopping in airports. Crawford & Melewar's (2003) works as an important reference for airport retailing, stating that stress, anxiety and normative traits should always be reduced and browsing induction should always exist, as well as pure impulse. Bamberger et al., on the other hand, gathered in their work five key success factors for airport retailing.

Finally, in terms of architectural layout, it is important to retain the idea from Freathy & O'Connell (2012) and keep in mind that people, in general, do not like to go back on their steps at any point and would rather avoid big detours from their way to the departure gate, which is their final destination. Van Oel & Van den Berkhof (2013) concluded that other architectural factors are also important, since pedestrians were found to prefer warm lighting, wide spaces, some greenery, some white presence, curvilinear roofs, curved hallways and no decoration related to the distinctiveness of the place they are visiting (in their case, Holland). However, Chebat et al. (2014) concluded that visitors' spending attitude is not too influenced by mall renovation, which was the main focus of their research.

Regarding the way individuals make a decision among a finite set of alternatives, several models have been developed throughout the years. Many of them are based on the Utility Theory, which defines a utility function and applies it to each alternative in the set; the higher the utility for a given option, the higher the probability for an individual to choose it. The utility function is said to have a deterministic part and an unobserved part; the probability for an individual n to choose alternative i in a multinomial logit model (which is most commonly used) is given by the formula in Equation (1) (Train, 2003):

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}} \quad (1)$$

Where V is the deterministic part of the utility.

Regarding the software tools that have been used throughout the years, it was possible to notice that AnyLogic is a very common option among the authors studying pedestrian and/or airport problems (Cheng, 2014; Curcio et al., 2007; Kalakou, 2012; Ma, 2013). Ma (2013), in particular, created an agent-based model for pedestrians inside an airport terminal using Bayesian networks and influence diagrams. Both processing and discretionary activities were included in his model, where activities were dependent on the passengers' basic traits and some environmental factors as well.

Methods

An analytical model would not have been possible in the aim of this research, since there are too many non-linear behaviours, events and time and causal dependencies in an airport terminal. A simulation model was thus used.

Having taken that decision, it became necessary to choose the type of modelling. In the context of this work, individual modelling is extremely relevant, since one of the main challenges was to model pedestrian behaviour in a realistic way. Hence, the possibility of creating an agent for passenger modelling and define all the necessary variables part of that agent became a very interesting characteristic to have in mind when considering agent-based modelling, since it allows the model to better represent more complex human behaviours. Furthermore, according to Grigoryev (2015), airports are placed in a medium abstraction level, which means that they can be studied through agent-based modelling, since this type of modelling covers a wide range of abstraction levels. In fact, this type of approach has proven to be an interesting option for modelling problems like the one treated by Ma (2013) and the one this research focuses on, namely because time-space dynamics are extremely important in an airport from a passenger's point of view, and those dynamics become easier to model in an agent-based model. A passenger is meant to be an autonomous and proactive entity who can analyse its environment, make a decision based on that and its personal characteristics and then create its own route towards the following target/facility. Each one of them has its individual variables but, in the end, all of these independent objects interact in order to achieve common objectives.

Some particular processes, however, need to be pre-defined by the user and undertaken by some of the entities (the passengers). In fact, the non-aeronautical activities mentioned throughout this text necessarily occur within the departing process of the passengers: they take place, more specifically, between the end of security check and the beginning of the boarding process for each individual. Such processes happen at specific moments in time and are the same for every single entity (passenger), who integrates them with a passive attitude. They can easily be modelled through punctual events and processes in the simulation system, making the discrete-event approach adequate to represent them. A multi-paradigm was thus needed in the aim of this work. This mix was mainly made out of agent-based components but included some discrete-event elements as well. AnyLogic was the chosen software tool in order to develop it.

The whole model for people behaviour is based on a task list: each pedestrian, when generated, has a list of tasks they wish to accomplish before boarding. The number and types of tasks each person has in mind depend on their personal characteristics. The general structure of the model, common to every single person who is generated by the simulation software, is the one represented in Figure 1. The different steps are thoroughly described in the following sections.

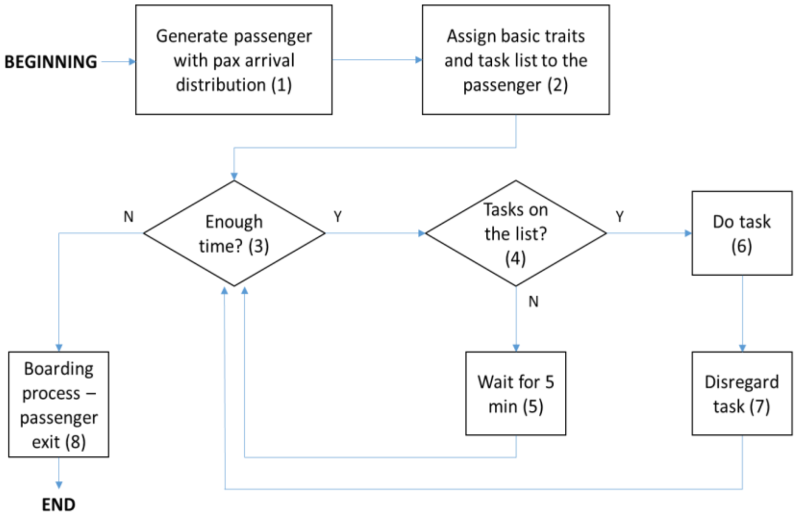

Figure 1. Diagram of the model's general structure for people's behaviours inside the terminal

1. Passenger generation

First of all, the individual is generated, according to a certain arrival pattern. At this point, the pedestrian has no specific characteristics or tasks in mind.

This step is done through the creation of an object in the model called PaxArr. What this object does is to define the time intervals between arrivals for three different periods of time for each flight, thanks to a function inside it: it considers that 25 % of the people arrive to the airport on the first third of the time, then 50 % of the people arrive on the following third and, finally, the remaining 25 % arrive on the last third of the period of time before departure. In order to do this, the function starts by defining an exponential arrival pattern for each one of the intervals of people and puts the values into an array list; it then uses a simple rule of three in order to calculate a time scale, which then multiplies by the previously determined values in order to convert them to an actual time dimension. This scale is calculated for the three arrival patterns and put into an array with size 3, by simply dividing the correspondent time dimension by the last arrival in that interval. In the end, the function calls an event that injects the correspondent number of entities into the passenger generator in the agent with the desired cadence. This distribution was adapted from the *Airport* example available in AnyLogic software and approved by researchers before being applied to this work. This function is called immediately on start-up of the object.

However, that procedure only defines a passenger arrival pattern to the airport. Keeping in mind that the model that is here developed only focuses on post-security events, it is necessary to somehow represent the time people spend checking in, dropping off their baggage, queueing for security and passing through it. This is done through a temporal delay right after the passenger generation which was set to a uniform distribution between 5 and 40 minutes.

2. Assignment of the individual basic traits and initial task list to the passenger

It is then necessary to assign that person their specific features and, subsequently, the tasks they wish to accomplish while inside the terminal. Two specific functions are called in the software – one that attributes specific characteristics to the passenger (travel class, sex, age, frequency of travel and whether they are foreigners or not) and another one that generates a task list from those specific characteristics and calculates the probabilities for each one of them to be undertaken. Obviously, the sum of all the individual probabilities for each activity on the list needs to equal 1 (unless the list is empty). Six types of tasks are here considered: eating/drinking, shopping, using a restroom, withdrawing money from a cash machine, ask someone for help and use an electronic device for social connectivity purposes.

A discrete choice model is used in order to determine such probabilities. It is inspired, more precisely, by the Utility Theory and the multinomial logit formulas in order to determine what the next task is at each moment. Instead of a typical utility function, another function is used. It was decided that this function would be called "propensity function", noted Prop, and would be defined by the intuitive formula in Equation (2):

$$Prop_{ni} = \frac{Priority_i}{distance_{ni}} \tag{2}$$

Being:

- $Prop_{ni}$ the propensity for an individual n to choose alternative i;
- $Priority_i$ the priority value of alternative i: a value between 0 and 100 which is illustrative of the dominance of some activities over others, in the sense that some might be, intuitively or statistically

speaking, more important for an individual to undertake in the first place than others. This concept and values are taken from Ma (2013);

- $distance_{ni}$ the distance (in meters) between the pedestrian location at a given moment and the point where activity i takes place. It makes intuitive sense that, the further away a given facility is, the less interesting it will be for an individual to undertake it, thus constituting the denominator of the fraction for the propensity calculation. This distance is obtained through the coordinates of the points and the classical formula taken from the Pythagorean theorem: given two points A and B with coordinates (x^A, y^A) and (x^B, y^B), the distance between them is given by: $d_{AB} = \sqrt{(x^B - x^A)^2 + (y^B - y^A)^2}$.

It is here assumed that equation (1) is still valid, but with propensities rather than utilities. Therefore, the passengers' choice process is still based on it. Probabilities for each alternative i to be picked by an individual n is thus given by the formula in equation (3).

$$P_{ni} = \frac{e^{Prop_{ni}}}{\sum_j e^{Prop_{nj}}} \qquad (3)$$

Depending on the passenger's basic traits, the probabilities of having a given task on the list vary substantially. Data for the percentages of people with each type of basic trait for the case study is obtained from Turismo de Lisboa (2014) and the associated probabilities that lead to the task list are taken from Ma (2013).

In order for each passenger to have these elements defined at an individual level, an object called Flight, as well as an object called Task and, of course, the Passenger agent, need to be defined in the model. Indeed, each individual pedestrian, as a Passenger agent, has inside it an associated flight (represented by a parameter belonging to the type Flight), a list of tasks (an array list with elements of type Task) and several other variables that are needed in order to represent all the priority, probability and propensity values at each moment.

The default value for all the propensity values is - 100 000, which is low enough in order to originate null weights and probabilities in Equation (3). If one gets a given task on the list, there is a variable called *task* inside the agent that switches from 0 to 1. Every possible task in the set has one of these variables associated to it, in order to define what propensities need to be calculated and which ones do not (the ones that are not on the list to start with).

3. Remaining time calculation

Remaining time until boarding is then calculated. If boarding has not started yet, the passenger considers that they have enough time to undertake at least one of the activities they might have in mind; otherwise, they start boarding straight away, which is point 8 of this sequence.

4. Remaining tasks on the list

If there is enough time, the pedestrian checks whether they have any tasks left to fulfil or not. If they do not, they go on to point 5 of this list; if they do, they go on to points 6 and 7.

In practical terms, an individual does not have any tasks on the list if all of the tasks have the associated propensity values equal to – 100 000.

5. Waiting period

If the person is generated with no tasks at all, or in case they have already done them all, they go to the main waiting area. Every five minutes from that moment on, and as long as the boarding process does not start, they check again whether they have something to do in their list or not. The reason why this constant verification is necessary is because people's hunger/thirst and need of using a restroom naturally increase with time. In fact, this is modelled through an event inside the Passenger agent, which increases the priority values for these tasks in a cyclic way every 10 minutes.

Priority variables have their debut values equal as the ones in Table 1. Four of these values were decided to be the same as the ones in the work developed by Ma (2013). For the other two, it is assumed that using the restroom is equal to eating or drinking in terms of priority, and that asking someone for help is less of a priority than that but still more than the rest, being therefore given the intermediate value of 65. The food and WC priority increment values are assumed to be 5.56 / 10 min and 8.33 / 10 min, respectively. These values were obtained through an intuitive reasoning where it was assumed that one would not consider using the restroom less than one hour after going there, and that one would not buy something to eat or drink again after less than one hour and a half after their previous purchase in a restaurant. In terms of priority values, this represents minimum values of 50 and 45, approximately (for WC and Food, respectively), before being considered as relevant again after having been set to zero before.

Table 1. Priority values in the developed model

Actions	Priority values
Buy a drink or meal	+ 100
Use the restroom	+ 100
Ask for help	+ 65
Shopping	+ 60
Emails, phone calls and social media	+ 40
Withdraw money	+ 30

6. Task selection

If the passenger has something to do, however, they need to select which activity they will undertake. That selection works through the probabilities that were previously calculated with Equation (3). A random number is generated between 0 and 1; depending on its value, it falls into a given interval of probability sum, which defines the chosen task to be done: supposing that there are N activities in the list, with probabilities P_1, P_2, …, P_N, the pedestrian chooses activity 1 if the random number is greater than 0 but smaller than P_1; if it is greater than P_1 but smaller than $P_1 + P_2$, activity 2 is the chosen one; that same reasoning applies until the last interval – if the random number is greater than $P_1 + P_2 + \ldots + P_{N-1}$ but lower than $P_1 + P_2 + \ldots + P_{N-1} + P_N$ (which necessarily equals 1), activity N is chosen.

The higher the propensity value of an option, the higher its probability is, making the associated interval broader and hence increasing the probability for the pedestrian to choose it. If there is more than one task, however, there is always a chance that the passenger ends up choosing another activity with smaller values of propensity and probability. This is how the model includes people's less linear or predictable behaviour. The time distributions associated to each activity are taken from Ma (2013).

7. Task elimination

After accomplishing a task, it is not considered as being part of the list anymore. At that moment, the task's propensity value is set to - 100 000 again and a function is called. All this function does is calculate the new distances, propensities and probabilities, taking into account the current position of the pedestrian in space and the tasks that are still on the list (the ones with the *task* variable equal to 1). In the case of the food- and WC-related tasks, priority variables are set to zero at that moment as well; in the case of the other tasks, the correspondent variables *task* are set to 0, so that they are not considered anymore in that function (there are some conditions in the code lines in order not to consider them). This is the way for the model to "delete" a task from the list, even though it does not actually delete it – in fact, it just turns it into an insignificant alternative, with null weights and probabilities. After that, the passenger goes back to point 3 of this sequence. The sum of the new probabilities (excluding the task which has just been done) is 1 and a new task is chosen inside this function. If there are any on the list and if boarding has not started yet by that time, that task will be undertaken next.

It is important to mention that, in the particular case of the activities related to eating/drinking or using a restroom, their priority values start gradually increasing with time from the moment they become null, and therefore the associated propensities take positive values again at some point. When their values become important enough, they might be selected as the activity to do next by the pedestrian. In other words: in those particular cases, the task is only deleted from the list until the priority value becomes greater than a certain value again; from that moment on, the task is back on the list again, until that necessity is satisfied.

8. Boarding process

This general cyclic reasoning goes on until the passenger reaches the conclusion that boarding has already started and goes to the assigned gate in order to have their documents checked and board. The model's attainability does not go any further from this point.

The boarding process, however, needs to be modelled as well. This is done through an object called Gate, since the whole process is complex and it is necessary to make it generic and applicable to several different gates.

Passengers only enter this object when the boarding process has started. However, they do not all go immediately to the gate control process – some of them prefer to wait before joining the queue. It is assumed that, from the moment when the boarding process starts, and while it lasts (except in the last 5 min), people follow a triangular distribution with its peak at one quarter of the boarding period, in order to reach the next step, which is the gate control process. In case the result of that triangular distribution is negative, they do not wait at all and immediately proceed to gate control.

Gate control, in turn, is cancelled as soon as the boarding process is over – at that point, the passenger is late and misses the flight. If everything goes well, on the other hand, the passenger moves on to a specific area of the gate until the moment boarding time has come to an end, which is a particularity of this case study. After that, the pedestrian moves on to the final step of this whole process, which is to actually board and disappear from the terminal.

Boarding and departure are modelled thanks to two events – one for the boarding process and one for the aircraft departure. The boarding event has in its parameters a Boolean named *begin* – when it is true (which happens when the boarding starts and while it lasts), the flight is added to a collection that contains all the active flights at a given moment; when it becomes false (when the boarding process is over), the flight is removed from that same collection because it is not active anymore and the gate control process is cancelled, causing the passenger to be late for the flight. The departure event takes place at the flight's departure time and all it does is remove it from the current list of flights. These events are created at the very beginning of each simulation run, depending on the specified schedule.

In fact, at the moment the model is run, several functions are called immediately on start-up: one of them reads the schedule defined by the user from a specified file and puts the departures into a collection of flights; another one defines, for each flight on the list, the three different periods of time for passenger arrival patterns; the last one creates, for each flight on the list, boarding and departure events. In order for this to happen, several temporal parameters need to be defined in the main working space of the software. These are all gathered in Table 2 and were also taken from the *Airport* example available in AnyLogic software. They were commented and approved by the same previously mentioned researchers before being applied to this work.

Table 2. Values for the time parameters in the applied model

Name	Value
Time from passenger arrival starts to departure	210 min
Time from check-in opening to departure	120 min
Time from passenger arrival finishes to departure	80 minutes
Time from high density arrival starts to check-in opening	15 min
Time from check-in starts to high density arrival finishes	15 min
Time from boarding starts to departure	50 min
Time from boarding finishes to departure	25 min
Minimum, mean and maximum values for the gate control process	5 s, 7.5 s, 10 s

Model verification

As described by Reis (2010), no model can remain untested if its creator wants it to be used by other people dealing with similar matters. Therefore, every model should, at least, be verified and, eventually, validated. In fact, these are two different concepts: according to the same author, verification consists of testing how much the model is working in line with what its creator has previously specified and assumed; validation, on the other hand, is more linked to reality and refers to the accuracy of the model results when compared to the ones originated by the real world system that is being modelled.

Being one of the main objectives of this work the modelling of individual choice behaviour, it makes sense that passengers should be studied individually before considering the model as being valid for a whole population of agents. Hence, in order for the model to be verified, this simple simulation was made repeatedly and extensively at every important step of the model construction. That was done by changing the schedule so that only one flight, with one passenger alone, was listed and generated. That one person could then be followed and studied by printing some variables' values on the software's console and checking whether everything was making sense and working as predicted at each step of the cycle or not.

Commands were thus given to the software so that the passenger's basic traits were printed, as well as the list of tasks and the initial values for propensities and probabilities. After that, values for propensities and probabilities were checked at every important step of the process as well, that is, whenever they were recalculated. At each point, the sum of the probabilities for the tasks that had not already been fulfilled had to equal 1. Values for the random number between 0 and 1 were also printed every time it was generated and the chosen task had to be in accordance with the probability interval where that number would fall into.

This was done several times, for a considerable number of individuals, with different basic traits and different task lists. The model was also shown to researchers other than the author (namely the author's supervisor) in order to receive exterior opinions and suggestions, since the modeller often ends up disregarding some of their own inaccuracies (Reis, 2010). It is noteworthy, however, that one can seldom verify their model with the certainty that it is working 100 % as expected – the modeller can, at best, build and grow a personal trust in the model and its output values, but it will always be, by definition, a simpler version of reality and can never represent it perfectly (Reis, 2010).

Performance indicators

The developed model aims to assess an airport terminal both from the passengers' and the managing entities' perspectives. Five types of indicators are here taken into account:

- Following the same reasoning as some authors from the past (Bandara & Wirasinghe, 1992; Tam, 2011), it is here considered that, the less the people are required to walk, the better it is from their points of view. Therefore, walking distance minimisation becomes an important objective of this research, applied to the described case study. This indicator is checked through the final value of a specific variable defined inside the Passenger agent: each time the pedestrian decides to undertake an activity (either one of the discretionary or simply wait for boarding), the distance to the destination is added to that variable. This also happens when the passenger finally boards – at that moment, the variable reaches its maximum value and does not change anymore. Of course, this value mainly depends on the initial list of tasks for each person and on the time they arrive to the terminal;
- Secondly, people should be able to fulfil all of the activities defined in the initial task list. This is measured through a variable specifically defined inside the Passenger agent for this purpose;
- Thirdly, for each studied layout, the number of people who miss their flights is taken into account. This number should be as low as possible for an alternative to be considered interesting;
- Also, for each individual, in case he or she leaves the system without having completed their initial list of tasks, it is interesting to know which tasks were left undone. In practical terms, these are the activities that appear on the initial task list but arrive to the end of the process with positive propensity values. Therefore, the necessary variables are created in order to work as counters for this: each one of them counts the number of people that leave the system without having achieved one particular activity they still have in mind at the moment they leave (one variable per alternative). This is interesting both from the individuals' and the managers' points of view, since it indicates what the most underperforming areas are for each alternative layout;
- Finally, from a managerial point of view, it is important to measure facility utilisation since it is, in a way, proportional to the revenues: it is considered that people who have "food" in their lists of tasks and have the opportunity of going to a restaurant necessarily end up buying something to eat or drink there; regarding shopping activity, on the other hand, there is no guarantee that people purchase something inside the shops when they visit them, but it is intuitively assumed that, the more people enter the shops, the higher the probability is that they end up buying something inside (either by impulse or because they pre-planned it). The other discretionary activities (using the restrooms, asking someone for help, withdrawing cash or using the internet) do not bring the same additional income to the managing entities, so only counter variables for shops and restaurants are here created.

Application to the case study

The model was then applied to the case study's geometry: four areas for restaurant services were created, as well as four shops, two restrooms, one service with line for the cash machine, one information desk (which is represented by the staff working just after security), one big waiting area (where the social connectivity task is assumed to happen, as well as the waiting period until boarding starts) and eight boarding gates (with eight service lines for gate control and eight specific waiting areas). This geometry can be seen on Figure 2.

Each facility or location has a pair of X and Y coordinates associated to it, except for the main waiting area, which is considerably big. Therefore, before calculating the propensity for that task, four distances

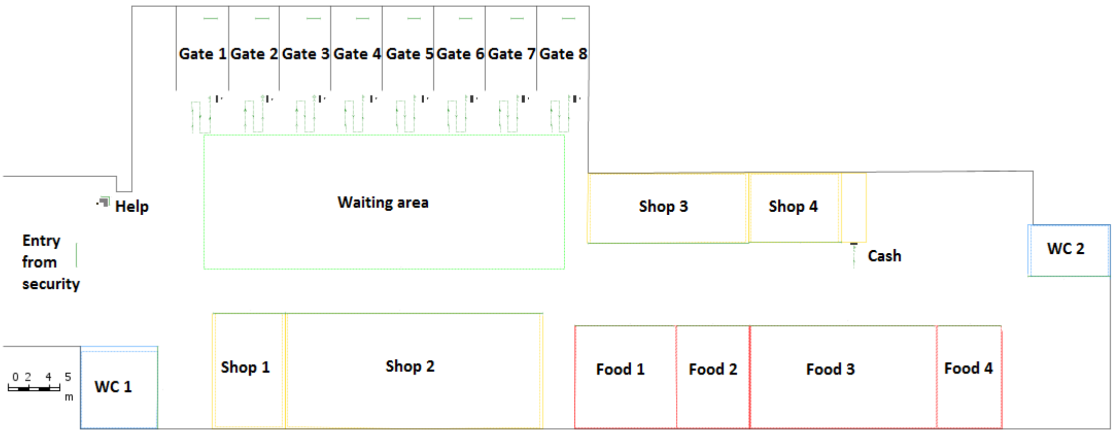

Figure 2. Plan of the terminal 2 of Lisbon airport in the developed model on AnyLogic

are calculated and, then, only the one with the minimum value is considered in the formula for the propensity determination. By doing this, the passenger will always evaluate how far the waiting area is through the smallest of the four distances, depending on where he is at a given moment.

It is assumed that, if a given person is willing to go shopping, they will visit either 1, 2 or 3 of the available shops. People who are willing to eat or drink, on the other hand, are considered to choose only one among the four available options. Regarding the restrooms, it is assumed that people do not have any preference between the two, and therefore propensities are always calculated for both as long as that task is on the list.

At the time the pedestrian enters the model, two values for the walking speed need to be defined by the user – one for the initial speed and another one for the comfortable speed. Several authors have made various proposals throughout the years, but the chosen one for this research work is taken from Schultz et al. (2010), who are mentioned by Cheng (2014) in her work. These authors recorded data from Dresden International Airport through video surveillance of an area located between check-in and security and analysed it statistically. According to the values cited by Cheng (2014), they concluded that the walking speed for an individual alone follows a normal distribution with mean 1.36 m/s. This was the adopted value for the comfortable speed in the model here described. Assuming that the initial speed is 0.3 m/s lower than the comfortable speed, its value is said to follow a normal distribution with mean 1.06 m/s.

In what concerns the simulation period, it was set to one entire day. In order to use real data from the case study, ANA official website (2015b) was consulted. The chosen day in terms of flight schedule was September 2nd, 2015. In order to have an idea about the number of passengers involved, the respective aircraft models were taken from FlightAware website (2015), through research of the flights' reference numbers, one by one; once the aircraft type was known, its configuration was checked on PlaneSpotters website (2015) and an occupation rate of 90 % was applied to it, since these are all low-cost flights. This led to a total of 6140 passengers generated during one of these simulation periods.

Results and discussion

Once the model was fully developed and verified several times, it was possible to run it several times and register the different performance indicators for several layouts. Each model was run 50 times, in order to try to eliminate (or, at least, reduce) the effects of randomness in the system. For each one of the performance indicators, the minimum, mean and maximum values were registered, as well as the standard deviation values.

Current situation

The first tested layout was the current situation. An average of 3805 people out of the 6140 in total managed to achieve their initial list of tasks, which accounts for 62.0 % of the people. An average of 2.2 % of the people, however, did not embark in their flights.

It was also possible to notice that Restaurant 1 was more used than Restaurant 2, which was more used that Restaurant 3, which was more used than Restaurant 4. The same happens with the number of people who wanted to use these facilities but ended up not having enough time for it: the number of passengers who wanted to eat in Restaurant 1 but did not have the time for it is lower than for Restaurant 2, which is lower than for Restaurant 3, which is lower than for Restaurant 4. The exact same thing happens to the shops, in the same order. It is therefore clear that Restaurant and Shop 1 are somehow more "accessible" than Restaurant and Shop 2, which are more accessible than restaurants and shops 3 and 4, respectively. Visually speaking, these facilities are numbered from left to right, as seen in Figure 2. So, the further away a restaurant or a shop is from the entry point in the system (after security), the less pedestrians actually use them.

Shopping activities tended to remain more undone than restaurant-related tasks, which was probably due to the difference in the priority values. Only 1.12 % of the people could not manage to fulfil the task "Help", which can be explained by its relatively high priority value, the short period of time it takes for someone to do it and the activity's position on the plan (right after security). The activities of withdrawing cash and using social connectivity, on the other hand, have the lowest priorities and therefore tended to remain less done, since time is limited. Food and restroom-related activities are the ones with the highest priority. However, more people leave the system without having used a restroom (when they needed to) than the ones who wanted to eat/drink but did not manage to. This can probably be explained by two main factors:

- Statistically speaking, more people have the "wc" task in their lists than the "food" task, because the probability for someone to use the restroom was set to be higher than for eating/drinking (70 % and 50 %, respectively), so there necessarily is a higher number of "unsatisfied" people regarding that activity. The other probability values connecting basic traits and activities were taken from Ma (2013);

- As stated previously, the restroom task becomes relevant to the individual approximately one hour after they used the facility for the last time, while that only happens in 1h30 for eating/drinking. Therefore, it is more likely that one ends up boarding with the "wc" task on the list than the "food" task.

Distance-wise, the absolute minimum walked distance was 7.2 meters (probably a passenger who needed to board at gate 1 and went directly there, either because of a late arrival to the airport or because they had no tasks at all on the list), the absolute maximum was 486.3 m (probably someone with a long list of tasks and enough time to spend on most of them, or all) and the average was exactly 100.0 m.

Alternative layouts – sensitivity analysis

In this section, some of the alternative layouts that were tested are highlighted, as well as their main results. The way the system reacts to these changes works like a sensitivity analysis, where the varying parameters are some of the facilities' coordinates.

Considering the observations that were made for the current layout of the terminal, it was decided that the first thing that could be changed in the layout would be the position of one of the available restaurants, since eating/drinking is a high-priority activity that often remains undone for people who wish to use this type of facility. After analysing the terminal plan and its physical restrictions, it was decided that Restaurant 4 (called Air Tasty 2 Go in reality) could be placed near the boarding gates. Motivation for this choice was that Air Tasty 2 Go is the smallest of the four restaurant spaces and thus the one that could more easily fit in that position, even if its area would need to be (slightly) reduced. By doing this, Restaurant 3 would see its area slightly increased, since it would extend to the space that is currently occupied by Restaurant 4, as seen in Figure 3. This option, however, was considered not to be interesting enough to be better than the current situation: although it would lead to a lower average walked distance and a substantially higher utilisation level for Restaurant 4, it would end up delaying the rest of the tasks, since the food-related activities are one of the most time-consuming and the ones with the highest priority value. In fact, all of the other options would become less performant from a passenger's point of view, in that more people would embark with a lower level of satisfaction because of not having completed them. Actually, the total number of people having achieved their initial tasks would slightly decrease as well. Shops, which have a lower priority value than restaurants, would have less visitors throughout the day because people willing to go to Restaurant 4 would mostly go there before dedicating their times to the rest of the tasks. Finally, the number of people who would miss their flights would increase by 10 people each day (to 3.49 % of the total number of people), which is a non-negligible increase. This alternative was thus rejected.

Two different alternatives were then tested for the cash machine's position: both of them would place it nearer to the main waiting area, but one would put it on the left side (seen from the same scope as in Figure 2), while the other would place it on the right. The latter one showed up as an interesting option, more than both the current one and the left position for the ATM: 10 more people would achieve their task lists every day, 28 less people would board without having undertaken the activity of withdrawing cash (meaning a variation of 4.56 ‰) and the walking distances would be slightly smaller (1 meter, on average). The rest of the parameters would not vary in a significant way. Although these changes are not too significant, they are still considered as being positive for the system and practicable.

In another tested alternative, the shop that was the furthest away from security was "pulled" to the middle of

Figure 3. Alternative layout – change in Restaurant 4's position

the main waiting area, in order to increase space and store penetration, as highlighted by Crawford & Melewar in their work (2003). The idea would be to build a kind of "kiosk" for people in the area and somehow "force" pedestrians to get past that point. This kiosk would be Shop 4, which is called Divers in reality (various items are sold there, such as newspapers, magazines, some souvenirs...). Shop 3 would thus increase its area because of the available new space next to it. The obtained figures show that Shop 4 would obviously become much more popular, with 245 more people visiting it each day and 246 less people boarding without having completed that activity (if they were willing to). The number of passengers who would not complete the "social connectivity" task would be reduced as well (1.30 ‰), probably due to the people who have both tasks on the list ("shop 4" and "social connectivity"), who basically would not need to walk to go from one area to the other. This layout would also lead to lower values for the walking distances (3.4 meters, on average), a positive variation of 2.93 ‰ in the number of people who would have achieved their initial task lists and a slightly inferior number of passengers who would miss their flights (even though it is too small to be considered significant). All the other facilities would get less users, but on a small scale. The most "harmed" facility would be Shop 3, since it would become the one furthest away from security, the main waiting area and the boarding gates. For all of these reasons, this alternative is also considered to be interesting, since it brings positive effects on several performance indicators, while it brings a lot more activity to Shop 4 and it creates a whole new dynamism around the main central area, where passengers necessarily walk through or past at some point of their journeys. Apart from Shop 3, which clearly becomes less relevant, it only affects the other facilities to some small extent.

A new alternative was then tested, consisting of the union of the two best ones previously described: at the same time that Shop 4 would change its position to the centre of the main waiting area, the cash machine would be put on the right hand-side of it (seen from above). After analysis of the results, it was possible to conclude that this would be an attractive option: in average terms, more people would achieve their tasks than in any of the previous options (4.23 ‰ more than in the current situation), the walking distance would be even more reduced (to an average of 95.1 m), Shop 4 would be much more visited than it is nowadays and less people would be unable to fulfil the "cash", "social connectivity" and "shop 4" tasks. Once again, the other options and indicators would only be lightly harmed or changed.

Finally, one last alternative was simulated for the retail space of Lisbon T2. It is, once again, a combination of different modifications: just as in the previous alternative, Shop 4 would be put in the middle of the main waiting area and the cash machine would be placed on the right of that area. However, instead of increasing Shop 3's area, Restaurant 4 would be moved to the current location for Shop 4 (which would not be there anymore), allowing it to be slightly closer to the boarding gates and the rest, as seen in Figure 4. Once again, the obtained results for this alternative were pretty satisfactory, since they represented not only considerable improvements when compared to the current situation, but also when compared to the previously described alternative, which was considered to be the best one so far.

In fact, it was possible to notice that this alternative would be better than any of the others in terms of walking distance minimisation (the mean reduction would be 8.2 m, so 8.2 % less than the current value); secondly, it is the one where the most people, on average, would finish their initially defined task list (7.65 ‰ more than in the current situation, which represents 47 more people per day); thirdly, it is the alternative with the most significant reduction of people who would not embark their flights (an average of 6 people per day); it also solves, in a way, the problem with Shop 3 that would exist in the two last previously

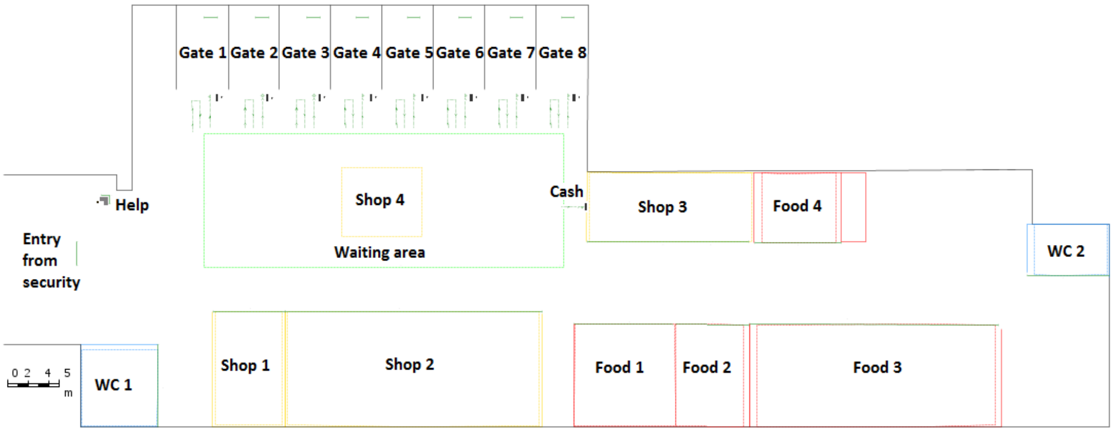

Figure 4. Alternative layout – combination of a change in Shop 4, Restaurant 4 and the cash machine's positions

described alternatives, probably because people who wish to eat at Restaurant 4 and enter Shop 3 would go more easily from one to the other and, furthermore, the total number of clients for Restaurant 4 would increase (because it would be slightly closer to the entrance in the system, i.e., security).

If this option was to be applied to the terminal geometry, the main results according to the developed model would be:

- No less than 61.5 % of the passengers would fulfil their entire list of tasks at least once;
- No more than 2.7 % of the passengers would miss their flights;
- Less pedestrians would leave the system without having used social connectivity or achieved the activities they wished to at Restaurant 4, the cash machine or Shops 3 and 4;
- Restaurant 4 would have slightly more visitors (6 per day), while Shop 4 would have many more (229 per day), thanks to its new location. This would certainly be interesting from a managerial point of view;
- The minimum, maximum and mean values for the total walked distance by the pedestrians would be some meters below their current values.
- The other facilities, however, would see their performance indicators get less attractive values but it is considered that these variations would not be harmful enough to the system to the point of "compensating" all the beneficial improvements. In fact, more passengers would leave the system with a higher level of satisfaction, and that is extremely relevant for an airport terminal too.

Conclusions

This methodology allowed the author to observe that some improvements regarding several aspects of the restricted area of the Lisbon T2 could be made: some facilities are less performant than what would be most desirable and the way facilities are disposed in space leads passengers to walk an average of 100.0 m, while an average of 2335 people leave the area without fulfilling their initial list of tasks even once. Some activities tend to remain undone more than others, but a general observation was made that, the further away from security a facility is located, the less people visit it on a daily basis.

After several alternatives were tested and assessed through the same set of performance indicators, it was possible to determine several possible improvements for the current layout. In fact, two modifications in different facilities would already be beneficial on an individual level but, when combined with each other, would lead to even more interesting results. These modifications would be the change of the cash machine's position to a closer location to the main waiting area and the placing of Shop 4 (Divers in the real world) in the middle of that same waiting area. By combining these measures to an extra change in Restaurant 4's position in order to occupy the current area destined to Shop 4, the system would become even more attractive in nearly every aspect, both from a passenger's and a manager's points of view: more people would catch their flights in time, more people would fulfil the tasks they had previously defined, some facilities would increase their utilisation rates considerably and pedestrians would need to walk less in order to induce these effects in the terminal.

The described model could however be improved and lead to more accurate results for the described study. It is important to keep in mind what is probably its biggest limitation: it does not take into account the different brands or product categories that are sold inside each one of these facilities, due to lack of available data about it for the case study. At the moment of a pedestrian's generation, if their personal traits lead them to want to eat, the probabilities of generating a task called "food i" or "food j" (with $i \neq j$) are equal, and the same happens with shopping activities. Therefore, no distinction is made between facilities of the same category, apart from the spatial position of each. In the case of the first described alternative layout, for instance, such a distinction would be important, since Air Tasty 2 Go sells more "portable" edible and drinkable options than the other three, allowing the passengers to purchase something there a few minutes before boarding if they wish to do so, or in case they are waiting for gate control in the main waiting area and become hungry again. Impulse purchases would probably end up increasing, which is not really taken into account in the developed model. This type of strategic reasoning regarding the facilities' positioning was considered one of the five key success factors for airport retailing by Bamberger et al. (2009) in their document about airport retailing and the best practices that need to be kept in mind in order to improve it.

In fact, no impulse shopping tendencies are modelled, since people have their lists of tasks defined at the same moment they are generated and they do not change from that moment on. The only way "impulse" shopping is considered is through the different facilities' positions, leading to a higher utilisation rate for some spaces than others, since one might decide to go somewhere and leave the other options on the task list for later because of their relative geometrical positions. This impulse shopping concept was also included among the performance indicators behind the assumption that, the more people visit the shops, the more likely it is that the sales increase overall, because of the people who spontaneously decide to purchase something they had not previously planned. Still, it was not directly integrated in the model.

Another limitation of the model is the propensity function: this concept was invented by the author. In future research, it might be interesting to create a utility function and calibrate it through specific surveys, such as the ones done by Denver International Airport (2009) but applied to this specific case study. This problem could have been approached in several different ways in terms of individual choice modelling options, which can be interesting for future work.

More specific conclusions to the case study can also be drawn by future researchers, namely if differences between facilities of the same type are considered and changes in positions are made while taking them into account, depending on the type of products and overall success each facility has among the passengers in the current situation. Some surveys can be made in future works in order to understand what the passengers' specific preferences are, depending on their basic traits. New statistical information can also be obtained in order to integrate impulse behaviour in the model and, eventually, make some profit calculations (in monetary terms).

To summarize: results can become more accurate and complete in the future if more data are added. In spite of these limitations, the developed model is still considered as being valid and interesting from a managerial perspective, since it leads to some important conclusions regarding spatial configuration of an airport terminal, while integrating a logical behavioural model for passengers that takes into account their (airport-specific or not) basic traits and relates them to the different discretionary activities inside such a space. The developed work allowed the author to detect some problems in the current state of the building and suggest alternative layouts that would somehow improve it as a whole. Thanks to the simulation capacities, all of this was tested and analysed through a screen, without having to make a single physical experiment on the field.

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