Automated airport check-in: developing an agent-based model

Cláudio Miguel Costa Esteves

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Supervisors: Dr. Vasco Domingos Moreira Lopes Miranda dos Reis

Dr. Maria do Rosário Maurício Ribeiro Macário

Examination Committee

Chairperson: Dr. Nuno Gonçalo Cordeiro Marques de Almeida

Supervisor: Dr. Vasco Domingos Moreira Lopes Miranda dos Reis

Members of Committee: Dr. Carlos Paulo Novais Oliveira da Silva Cruz

: Dr. Amílcar José Martins Arantes

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Abstract

Need for airports to improve capacity by optimizing spaces and the need for airline carriers to bring down their operational costs creates the opportunity of increasing the use of self-service technologies at the passenger check-in process. Developments such as kiosks alongside automatic baggage drop-off are gaining ground in the short-term. While self-service technologies promise to offer flexibility not only to the user but also to the airport planer, short-term developments must be approached according to technological advances and the airports' masterplan. Simulation is used to test certain scenarios and adopt the most valuable solution. Models of pedestrian movement and pedestrian flows have been used in simulation for years. Most treat the agent as an individual agent that does not fully interact with the environment. Several models and simulation tools exist to study flows of people inside complex areas, but the focus is only in one behavior of the pedestrian: the navigation. Passengers' profiles affect how they interact with the environment, especially when presented with self-service solutions. Develop an agent-based model to represent and assess how distinct passengers' profiles affect check-in area service level in terms of quality and efficiency when more recent check-in solutions are introduced is the objective of this research. The model can better reproduce the pedestrian inside the airport by representing interactions between agent and environment. The model is applied to Lisbon Humberto Delgado's airport departure hall concluding automated airport check-in affects positively the terminal's performance by reducing in half queue waiting times.

Key-words: Airport; Check-in; Self-service; Baggage drop-off; Modeling; Interactions; Agent-based model;

Resumo

Com a necessidade dos aeroportos em aumentar a sua capacidade e a necessidade de as transportadoras aéreas reduzir custos operacionais surgem oportunidades na implementação de soluções self-service ao nível do check-in. O *kiosk* e os balcões automáticos, como soluções inovadoras, são opções cada vez mais utilizadas em aeroportos. Estas soluções oferecem flexibilidade para o gestor aeroportuário, contudo, a sua implementação deve seguir diretivas do planeamento aeroportuário e estar de acordo com outras tecnologias implementadas. A simulação como ferramenta para estudo de sistemas complexos é bastante útil para testar novos cenários. Os modelos por agentes para simular o peão num sistema complexo têm sido amplamente utilizados no mundo da simulação. A maioria trata o individuo como um agente incapaz de interagir com o ambiente circundante, focando-se no comportamento de navegação. Com diferentes perfis de passageiros que adotam tecnologias de formas distintas. O objetivo é desenvolver-se um modelo de agentes para representar e avaliar como os diferentes perfis afetam a performance do terminal aquando da introdução de novos métodos de check-in. Por permitir interações entre o agente e o ambiente o modelo proposto consegue uma melhor representação do peão dentro do aeroporto. O modelo, aplicado ao aeroporto Humberto Delgado, conclui que a introdução de balcões automáticos pode reduzir o tempo de espera médio em filas para metade e que no geral afetam positivamente a performance do terminal.

Palavras Chave: Aeroporto; Check-in; Self-service; *Drop-off* de bagagem; Modelação; Interações; Modelo por agentes;

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Acronyms

- ABM – Agent-based model
- ABMS – Agent-based model simulation
- ASQ – Airport Service Quality
- CUCC – Common use check-in
- CUPSS – Common use passenger processing system
- CUSS – Common use self-service
- IRSS - intelligent resource simulation system
- LCC – Low Cost carriers
- LCT – Low cost terminal
- LOS – Level of service
- NFC – Near field communication
- SST – Self-service technology

Chapter 1 – **Introduction**

Passenger experience and motivations are critical aspects that affect service quality of an airport. The first chapter of this research depicts this research by explaining author's motivations, reviewing methodological approach and objective of the present document.

1.1 Motivation

When air transportation becomes the fastest way to travel in a globalization era, airports become essential to provide transfer form ground-to-air and vice-versa. Air transportation volume keeps growing each day, resulting in more airplanes, newer routes and more air passengers. Adding the fact that airlines are struggling to thrive in the market and some are even adopting different operational standards, it increases the entropy and the requirements for every player of air transportation. Airports are the most important link for an air passenger, and with the view to reduce operational costs, maintain level of service and adapt to airlines operational rules and requirements, data analysis should be conducted.

Analysis of real case scenarios have been made over the years among air transport industry, especially inside airports, usually to improve service quality or to test new scenarios. However, studies concerning the system itself rather than what is in that system – the pedestrian – do not create accurate representation of the reality. Digitalization, smart systems and the decrease cost of computing power boosted air transportation to follow the trend of self-service with online and smartphone apps technologies. All these improvements have one thing in common, the intention to fulfill passenger needs while improving efficiency and reducing operational costs.

Models of pedestrian movement and pedestrian flows have been used in simulation for years. Most treat the agent as an individual agent that does not fully interact with the environment (e.g. Lin 2014; Ma 2013). Several models and simulation tools exist to study flows of people inside complex areas, but the focus is only in one behavior of the pedestrian: the navigation. Then, the environment and the interactions are only considered as a set of objects to avoid while moving. Impulsive actions are a universal phenomenon among pedestrians. Almost 50% of the activities in airports are unplanned (Kalakou 2016) with 60% of passengers being impulsive buyers (Geuens et al. 2004).

In airports, one can always perceive the following scenes: a passenger inside the terminal, while moving to the check-in area stopping to drink a coffee, a passenger looking for a shop and entering; and a passenger seeing a kiosk and performing check-in there. Such moments reveal that airports are complex systems in which interactions with the environment take place and are recurrent. Therefore, it is necessary to consider passengers as transients that interact and may perform activities when perceiving the environment.

. Check-in process, which remains an important process on the landside area, is undergoing several technological upgrades becoming more and more automated. The question is how distinct acceptances, created by different passengers' profiles, could affect the performance of the terminal by introduction of fully automated counters. When:

- A new option is presented inside the terminal, the passengers must decide whether to use it or not;
- Passengers' profiles affect the way they perceive technology; and
- Solutions can only bring improvements if the user sees benefit and uses it.

A model for pedestrians inside the airport terminal could help determine how the system will respond to upcoming trends and developments.

1.2 Objective

The main objective of this dissertation is to develop an agent-based model to represent distinct passengers' profiles and assess terminal gains when more recent technology is applied to check-in area. Primary research question needs to be answered:

- What are the expected changes inside an airport terminal?
- How do people behave and interact with the surrounding environment?
- What are the simulation run results and what do they point out?

Applying an agent-based model on the airport terminal's landside[1] of Lisbon airport is the scope of this dissertation. The reasons why terminal's landside is used for this research are: (1) it is the area in which the passengers perform the check-in - one of the most relevant aeronautical processes; (2) passengers in airports have diverse characteristics and are presented with a diversified set of objects and facilities, therefore interaction is possible making it a perfect environment for studying agent behavior dynamics; and (3) Short-term forecasts indicate terminal's landside is undergoing several technological upgrades.

1.3 Methodological approach

The methodology used to achieve the goals of this dissertation can be summed up as the following six steps:

- Literature review;
- Model learning;
- Data collection;
- Model development;
- Case study observation in loco; and
- Simulation runs and result analysis.

A valid conceptual model is needed to achieve the objective of this research. To assure that most model assumptions in this research are grounded on results obtained from the

[1] Airports are divided into landside and airside. Landside includes areas such as check-in, parking lots and access transportation nodes. Landside and airside is divided by a security screen.

literature. Several pedestrian modeling methods are compared resulting in the most adequate method – the agent-based modeling is the preferred. The model was created using AnyLogic® platform and the model logic was adapted accordingly. A proper calibration was needed to ensure the model reflects today's operation of an airport terminal. Once the model is completed and implemented, different scenarios were tested to collect data and information. The key is to understand how the terminal will perform under certain scenarios and assess operational gains.

1.4 Dissertation Structure

The structure of the dissertation takes form in five chapters, including this initial one. The rest is organized in the following way:

Chapter 2 by performing the **literature review** is aimed to understand the system environment and model approaches. **Model learning** was obtained by reviewing literature on how to model pedestrians.

Chapter 3 presents **model development,** its principles and all the **data collected** to build the model, the validation of the model and how to implement the model in the simulation software.

Chapter 4 presents the **data collected** from airport case study (in which the model will be implemented). Testing scenarios will be discussed, results are presented. After, **simulation runs** are performed, **result analysis** is performed.

Chapter 5 concludes this dissertation and provides future research recommendations.

Chapter 2 – **Literature review**

The present chapter will research the check-in area and modelling approaches. Explaining first the context where the check-in emerges inside the airport. Passengers profiles is discussed and then the check-in area is reviewed to explore all the process and to understand the trends and the most advanced solutions applied to it. Afterwards the focus will be on modeling for pedestrians and to understand all underlying principles for pedestrian modeling to be applied in airports.

2.1 Airport landside

The airport is one node in a larger system, in fact it is a fundamental part of the air transport system, providing infrastructure to enable both freight and passenger transfer from terrestrial to air mode (Graham 2014). The need for airports derives from the improvement of aircrafts and its search for an adequate airfield that could provide proper support and safety. Aviation passengers and cargo traffic had had a notable growth during the last half of the twentieth century with the last 20 years having strong growth rates leading to double the passengers in this period which severely congested the European airspace (Kazda & Caves 2015; de Neufville & Odoni 2013). Nowadays, airports exist and are designed in the context of meeting airline companies' criteria. Airports serve a wide variety of users and its facilities need to operate efficiently over the 20 to 50 years of their lifetime, hence the necessity to understand the current and the prospective needs of the users and the airlines' requisites (de Neufville & Odoni 2013).

An airport is primarily separated into two key elements, the landside and the airside. The airside is the place from which aircrafts operate, it is the sum of all infrastructures, facilities, processes, agents and equipment required to support aircraft takeoff (de Neufville & Odoni 2013; Kazda & Caves 2015; Graham 2014). The landside is the sum of the areas available for the passenger departure and arrival with all the infrastructures to support these activities. The airside- landside threshold is marked by a security screen (Kazda & Caves 2015). For departing passengers, the landside includes the areas they use since arriving to the airport until pass through security screening. Transit passengers usually only use the airside facilities that enable them to connect to their next flight, sometimes the same area is used for departing and arriving passengers (Kalakou 2016).

Terminal building needs to provide not only facilities for mode transfer from ground-to-air and vice-versa, but also air-to-air, making it an essential element of airports' infrastructures. To achieve the best terminal design the following considerations should be taken into account (ACRP 2010):

- Mission of the airport;
- Balance;
- Level of Service;
- Passenger convenience;

- Flexibility;
- Security;
- Wayfinding;
- Accessibility; and
- Maintenance.

2.1.1 Terminal building

Airport's passenger terminal performs a key role in the airport activities serving its users in a fast, safe and efficient manner. Passengers and those who accompany them need to perform some tasks within the terminal to board the airplane so, providing circulation, processing and holding space are the main functions of the terminal. According to Kazda & Caves (2015) the terminal needs to guarantee convenient facilities for mode transfer and frontier activities. In detail, the terminal building (Figure 2.1) functions are:

- Airside connection;
- Connection to the landside transport systems;
- Information for the passengers throughout their course;
- Shortest possible walking distances for all types of passengers;
- Convenient and comfortable connection for transfer and transit passengers;
- Baggage handling system for local and transfer bags;
- Appropriate security screen; and
- Appropriate size for all areas.

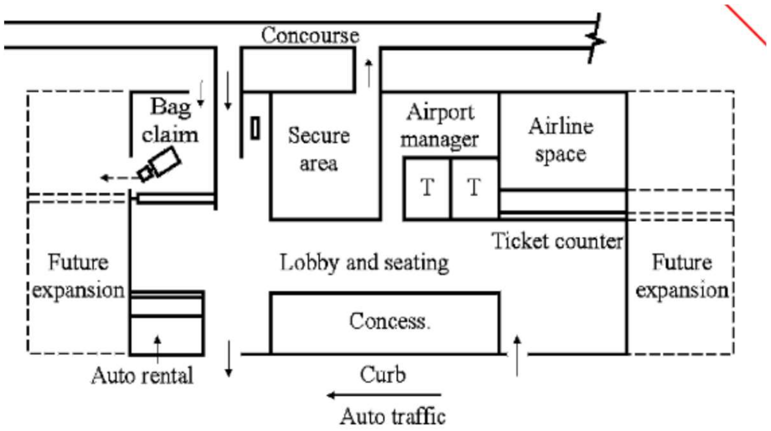


Figure 2.1 - Example of a functional terminal layout.
(FAA Advisory 1980, sec.4).

IATA (2004) refers the following subsystems form the airport terminal building:

- **The main passenger processor** (departure concourse and check-in areas for departing passengers; baggage reclaims and arrival concourse for arriving passengers);
- **Outbound and inbound government inspections services** (passport control, security checks, health checks and customs control);

- **Holding areas** (centralized – main departure lounge, dispersed – e.g. finger-piers); and
- **Concession areas** (both landside and airside).

An airport passenger terminal cannot be planned in isolation in fact, efficient planning considers the overall environment in which the facility will be developed and other aspects such as: Airport master plan, land use compatibility, ground access transportation, terminal site planning, airport security, information technology and communications, environmental protection, sustainability and business planning (ACRP 2010). And, however well a terminal is designed, it must be operated properly to achieve its purpose.

Terminal buildings have been in continuous development and improvement based on its demands. Ashford et al. (2011) states three major factors as the improvements' source: advancing in aircraft technology, huge growth in passenger traffic and improvement of service quality. Nowadays, terminals are struggling to keep up with demands and need new innovative ways to deal with uncertainty. Ashford et al. (2011) remarks the need for airports to create new revenues providing different services beyond their initial functions.

2.1.2 Users of airport terminal

According to Ashford (2011) the terminal has three principal user classes:

- Passengers and those who accompany them (visitors);
- Airline operators; and
- Airport operators.

Passengers will be discussed next, as for visitors, they use the airport to accompany the passengers until they enter the security check. Visitors can also be attracted by shopping services (on the landside). Airline operators are workers from the airline that use the terminal to arrive to their working station (e.g. Check-in counters, boarding gates and ticketing offices). They prefer to move fast and have own security control. Airport operators include police workers and security who ensure the secure operation of the airport. The airport logistic agents and ground handling agents have various work positions, and as the airline operators, need to move fast to arrive to their working stations.

Passengers

Passenger segmentation is needed since airports are used for several purposes and as Pantouvakis (2016) remarks "the measurement of service quality and satisfaction issues should not treat (…) invariantly people of different populations". According to Félix (2015) and Kalakou (2016) the categories are: role of the airport, trip destination, trip purpose, holding baggage or not, flight type and group size. Group dynamics is out of scope on this dissertation.

<u>Role of the airport in the journey</u>

- Start point – passenger's journey starts in the airport.

- Transfer passengers – Passengers who use the airport as a transfer's node between the origin and destination point. They require fast, reliable and easy to find connection between the two flights (Kazda & Caves 2015).

Destination

- Domestic flights – passengers moving inside the same country.
- International Schengen flights – passengers moving inside the Schengen area need no special government control.
- International non-Schengen flights – passengers require governmental control.

Trip purpose

- Business – Usually frequent flyers, extremely used to the airport environment and with less baggage. They require fast check-in and the shortest walking distances to their destination (Kazda & Caves 2015).
- Leisure – Passengers who travel with greater number of luggage and who tend to arrive early to the airport.

Baggage or not

- Baggage to be checked-in – Passengers need to check-in their luggage, either with the use of a counter or a drop-off point.
- No baggage to be checked-in – Passengers are related to frequent flyers with short period trips and late arrivals to the airport.

Flight type

- Regular – Passengers have no specific requirements for types of services.
- Low Cost – Passengers usually with low requirements in space.
- Charter – Passengers with overweight baggage.

Group size

- Single passenger.
- Group of passengers.

Passengers also vary in socio-demographic factors, and may perceive technologies differently. Therefore, passengers use the terminal differently. First, younger passengers are in favor of the use of self-service technologies and against traditional solutions. This young generation propensity to use self-service technologies is shown in Castillo-Manzano & López-Valpuesta (2013). Young generations spend most of their free time on their computers and mobiles and use modern technologies as essential tools for communication and information. It is suggested that this generation seems to embrace technology first (Nickson 2016). Also, other findings indicate elderly people prefer human touch to process aeronautical duties (Castillo-Manzano 2010).

Passengers who use their smartphones require less printed documents (tickets, boarding passes and luggage tags) having more digital interaction. With rapid advances in technology and the development of smartphones, passengers adopt newer and distinct behaviors and habits (Nurus 2017).

SITA Passenger IT trends (2016) acknowledge distinct types of passenger dividing them into four profiles (Figure 2.2): (1) Careful planner; (2) Hyper connected; (3) Pampered; and (4) Open-minded adventurer.

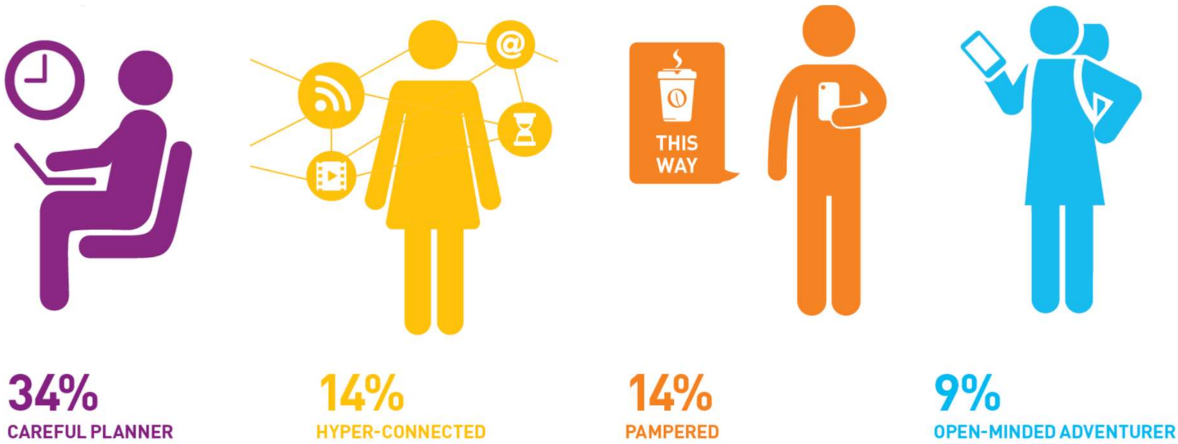


Figure 2.2 - Passengers profiles SITA (2016)

Despite distinct profiles, passengers show preferences to technology rather than people. Passengers using a certain self-service technology to check-in will have 91% to use it the next time. Findings indicate that if a passenger meet some self-service technology for a certain step, that same passenger would return to that same self-service technology rather than to the traditional face-to-face method. Usefulness and ease of use are encouraging people to adopt travel technology (SITA 2017).

2.2 Passenger processes and activities

Airport terminal building emphasizes on passenger needs i.e. focus on passengers' processes that they need to perform over the terminal to reach the airplane. A process is "a series of actions or operations conducing to an end" (Merriam-Webster.com 2017) this definition has similarities and converges to others presented over the literature (Magalhães 2014). A process consists of a sequence of sub-processes that conduct to an end, consuming resources (time or human/equipment or financial). Each process has its own activities which are not positioned randomly, they need to be continuous following its own sequence (Magalhães 2014). Different processes' configuration may lead to distinct levels of time, human/equipment or financial, efficiency. This representations, used to simplify airport terminal operations, are then used to model and simulate airport terminals (Guizzi et al. 2009; Curcio et al. 2007; Olaru & Emery 2007; Magalhães 2014).

Several processes schemes can be found over the airport operations since it involves passengers, luggage, cargo, aircraft movements, ground handling and crews. The passenger building accommodates processes related to passenger departure, transfer and arrival. While on the terminal the passenger must perform his aeronautical activities however non-aeronautical activities may be performed as well. Since the departure hall is the focus of this dissertation, only the departure process will be explained in the following section.

2.2.1 Passenger departure

Presented on Figure 2.3 is a typical flow diagram for passengers' process at airports terminals. It is important to consider Schengen and non-Schengen passengers. Schengen process is less complex when compared to non-Schengen as immigration service is not needed. Normally for departures, passengers perform check-in before the arrival at the airport or in the airline's area, pass security controls, proceed to general lounge an then go to the gate holding area (Magalhães 2014).

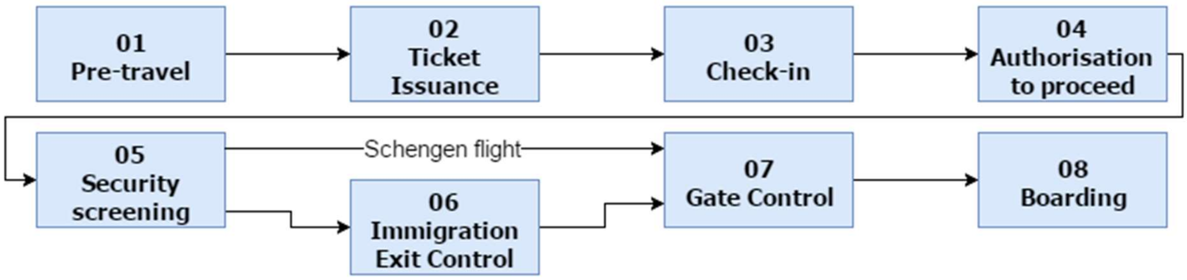


Figure 2.3 – Schematic representation of passenger processing adapted from IATA (2011).

Steps 1 and 2: Pre-travel and ticket issuance

Before passenger terminal arrival such as: destination choice, route choice, schedule etc. In 2008 all tickets were issued electronically (IATA 2017) as it proved to be more convenient for passengers who no longer have to worry about losing tickets and can make changes to itineraries more easily.

Steps 3: Check-in

A sub-process whose main purpose is to identify de passenger, attribute a seat in the airplane, dispatch baggage and issue the boarding pass. The check-in process has been undergoing several changes during the last decade and it will be addressed in detail on further section.

Steps 4 and 7: Authorization to proceed and gate control

Steps meant to check if the passenger has a valid boarding pass to prevent his advance to the wrong terminal or plane.

Steps 5: Security screening

The existence of a security screening is essential to detect potential safety threats. The 9/11 terrorist attacks, led to extensive security screening and often invasive processes i.e. body scanners to identify prohibited items. There is also a check of the personal belongings over an X-Ray machine. If there is any suspicion, an authorized employee will personally scan the person. The security screening is likely to change in the future due to traffic growth (Kalakou 2016).

Steps 6: Immigration exit control

Based on regulations, border controls differ when entering and exiting each country i.e. in Europe, passenger and goods are allowed to travel freely within the Schengen zone but international non-Schengen passengers are obliged to pass through immigration and border control.

Steps 8: Boarding

Finally, passengers and their baggage will board the airplane either by jet bridge or transfer. It is a key activity since punctuality is a key performance indicator for both airports and airlines.

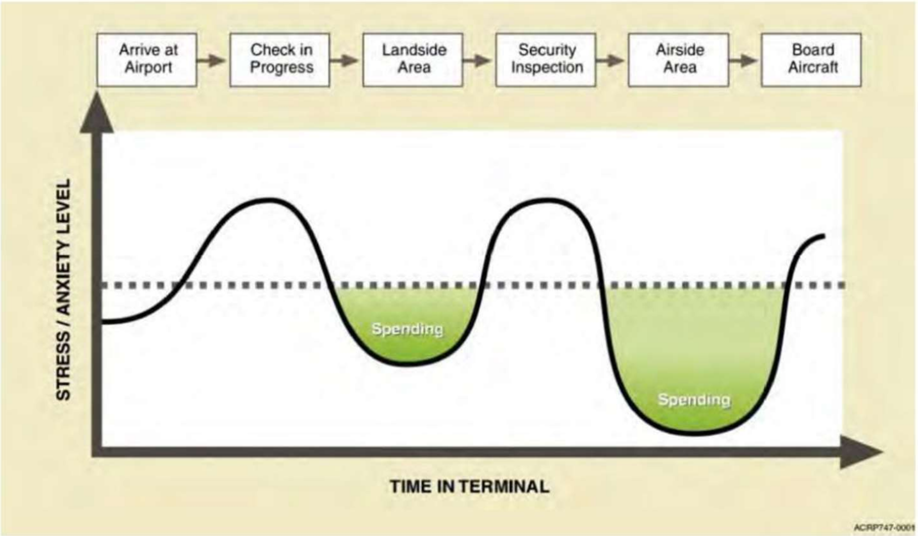
2.2.2 Discretionary activities

Discretionary activities emerge from the fact that it is necessary to accommodate the passenger's needs and not to focus only on the main reason why people come to airports: to travel somewhere else. Thus, it's necessary to create a pleasant and familiar environment for the passengers. Discretionary activities have gained increased importance due to the non-aeronautical revenues they generate. Lately the idea of an airport not only as part of the transportation system but also as part of the city has created new opportunities for discretionary activities in passengers terminals (Graham 2014).

The extent of discretionary activities is correlated with the space available and the type of airport. A simple duty-free retail shop provides a minimum level of service however, with the need to increase revenue other types of stores can be find. Nowadays, there is a wide range of services that range from fashion, electronic and gadget stores and several catering options to hotels, supermarkets and fitness centers. The retails can be placed anywhere in the airport area but it is required that discretionary activities don't disturb the smooth running and basic functions of the airport. The increased scope of services ease the airport's operation as the offered activities divert passengers from the main circulation streams and help distract from the aeronautical problems and irregularities that may occur (Kazda & Caves 2015). This development encourages strategies that decrease the dependence of airports on aeronautical revenues (Graham 2014).

Orth et al. (2015) suggests the increasing number and scope of discretionary activity centers found around the airports has led to transportation hubs having to serve not only the airport users but also the surrounding region which is creating a substantial number of visitors' trips to and from the airport. The same author concludes that discretionary activities around the airport create a favorable situation for the operation of public transport services in the airport and remarks that these movements have not yet been studied in detail.

Performing activities is intimately related to time availability (Castillo-Manzano & López-Valpuesta 2013). Lin and Chen (2013) found that passenger shopping motivations had positive impacts on the commercial activities at the airport, his findings relate time pressure and impulsive buying as factors to prompt shopping motivations. In fact, air travelers are seen as impulsive buyers. According to Geuens et al. (2004) 60% of travelers are impulsive buyers and Topping (2010) estimates around 30% of airport purchases are made on impulse behaviors. Being at an airport increases the anxiety levels which is caused by time-stress and the unfamiliarity with the airport. Therefore, the state of anxiety (Figure 2.4) affects the shopping behavior and is variable while inside the terminal (Kalakou 2016).



Source: LeighFisher.

Figure 2.4 - Passenger stress and willingness to spend Kalakou (2016).

Discretionary activities represent a key role in future airport terminals, and many opportunities are yet to be created and explored. These opportunities can be presented inside the terminal, providing a wider range of services and outside the terminal for transportation systems and real-estate development around the airport (Ashford et al. 2011).

2.2.3 Airport performance and quality indicators

To ensure an adequate airport performance, guidelines were developed for the airport's planning and design. These guidelines, proposed by IATA, help guarantee the good functioning of the terminal. These guidelines were established based on an adequate level of service (LOS). The concept "Level of service" classification (Table 2.1) is based in measurable indicators i.e. space and waiting time.

Table 2.1 - Level of service characteristics. Ashford et al. (2011).

LOS	Quality of service	Passenger Flow	Delays	Comfort
A	Excellent	Free	No	Excellent
B	High	Stable	Very Few	High
C	Good	Stable	Acceptable	Good
D	Adequate	Unstable	In Short periods	Adequate
E	Adequate	Unstable	Unstable	Inadequate
F	Unacceptable	System breakdown		-

LOS refers to the quality of the space in which every activity takes place. Design for LOS C is common for planners, so that only in the worst situations it fell for LOS D which is acceptable in short periods (de Neufville & Odoni 2013). As the design is planned for some expected time horizon, it is common to find LOS A when the terminal opens (de Neufville & Odoni 2013). The LOS also includes check-in facilities (Table 2.2).

Table 2.2 - Check-in facilities LOS guidance.

	A	B	C	D	E	F
Check-in queue area [m²/occupant]	1.8	1.6	1.4	1.2	1.0	-
	Short to acceptable		Acceptable to long			
Check-in economy [min.]	0-12		12-30			
Check-in business [min.]	0-3		3-5			

More recently, in 2014 IATA released a new concept of airport LOS based on time-space concept (Figure 2.5). Instead of focusing merely on space to measure service quality and passenger comfort, this new concept also includes waiting time in the LOS concept. Four new levels can be achieved: under-provided, sub-optimum, optimum and overdesign. The need for a new concept arises from observation of oversized terminal facilities trying to provide passenger LOS A during all operational periods. This resulted in overdesigned and costly terminals (Kalakou 2016). New LOS concept already considers self-service check-in solutions (Figure 2.6).

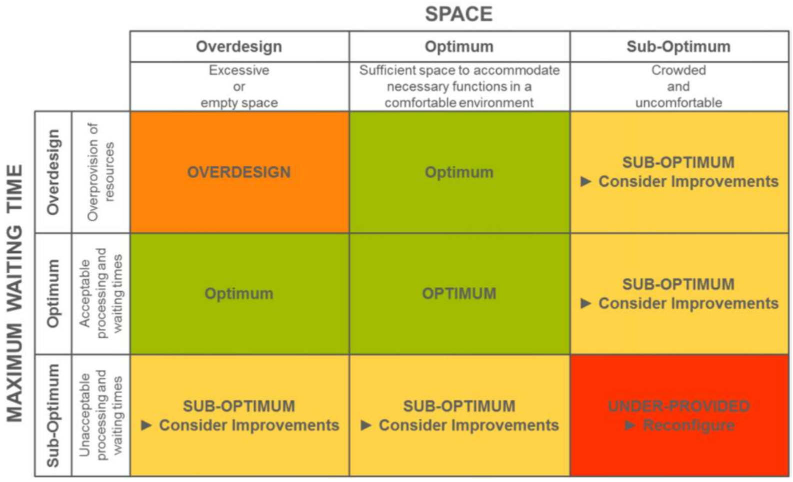


Figure 2.5 - New IATA LoS concept (2014).

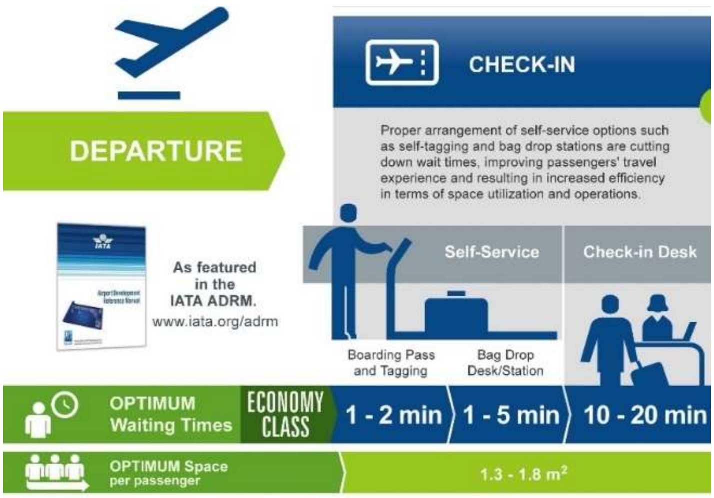


Figure 2.6 - New IATA LOS concept to check-in excerpt.

Customer satisfaction and service quality are intimately related to airport performance and therefore passenger inputs are of great importance. Customer satisfaction and service quality are subjects of high interest within the airport industry. International agencies must systematically use surveys to assess how passengers are perceiving airport quality. Airports have become more and more complex offering a wide range of services and passengers are demanding higher levels of service. It is then of great importance for airport managers to measure, analyze and retrieve relevant information regarding passenger's perception on Airport Service Quality (ASQ) (Bezerra & Gomes 2015).

Factors such as indoor environment quality (thermal comfort, air quality, lightning and acoustic) researched by Geng et al. (2016) and passengers expectation (speed of delivery, ease of use, reliability, enjoyment and control) researched by Chang et al. (2008) and others are of great importance to improve airport performance. Even though these factors are out of the scope of this dissertation, the author acknowledges the importance of these factors.

2.3 Check-in

Check-in is a mandatory sub-process within the passenger departure process and it is crucial for terminal's operations. The check-in is the process where the passenger has the ability to make a reservation on a specific seat of the airplane and deliver (or not) his baggage. Traditionally, check-in is provided on a counter by an employee who confirms passenger's information (ticket and I.D) and receives the baggage. The baggage is then checked for all the requirements (weight and size) and tagged properly. It is a service that can be provided by the airport, the airline or by a third-party handler (de Neufville & Odoni 2013). Airports and airlines want to provide smooth check-in operation and ensure a high-quality service for passengers. From passengers' perspective, check-in is related to the negative perception of waiting (Wittmer 2011). The introduction of electronic ticketing and self-service check-in procedures has revolutionized the airport facilities (Ashford et al. 2011). Currently the trend is to use self-service technologies (SST). Statistic shows SSTs are thriving on airport terminals and enable more efficient terminals when used in airports (SITA 2016).

2.3.1 Check-in process

Check-in process (Figure 2.7) has been subject to several changes not in terms of the activities but in terms of where and how the passenger performs them. Kalakou (2016) suggests the division of the check-in in two sub-processes: check-in and baggage processing since it's not mandatory to complete baggage processing and there's the possibility to go over the two sub-processes in distinct places at different times.

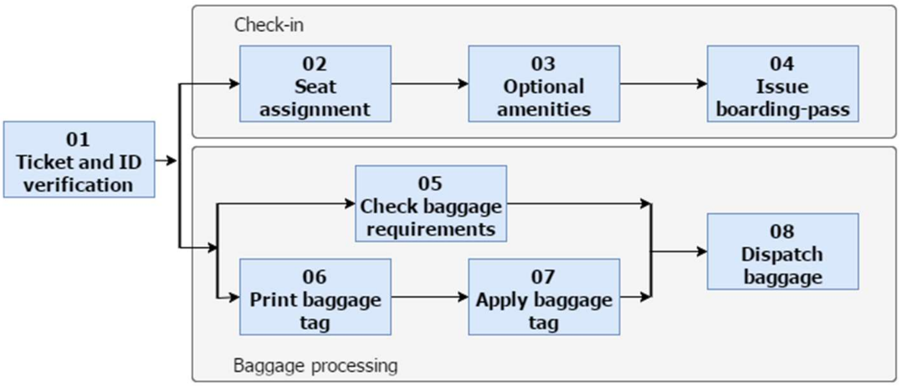


Figure 2.7 - Check-in process.

Check-in process can be achieved by many different check-in solutions (Table 2.3). Solutions presented and explored in the next section are divided into four main categories: traditional counter, Drop-Off counter, kiosk and online. In each solution, it will be discussed the technological developments that improve their functionality.

Table 2.3 – Activity provided by each check-in solution.

Sub-process	**Activity**	**Counter**	**Drop-off counter**	**Kiosk**	**Online**
Check-in	Seat assignment	X		X	X
	Optional Amenities	X		X	X
	Issue Boarding-pass	X		X	X
Baggage processing	Check Baggage requirements	X	X		
	Print baggage tag	X	X	X	X*
	Dispatch baggage	X	X		

** Needs recent baggage technology*

While the check-in counter can manage to offer all services, the kiosks can only print baggage tag and needs to be followed by a drop-off baggage counter and the online check-in is best suited for non-baggage dispatch. The inability of dealing with luggage, is the main reason why check-in facilities still need to operate. Graham (2014) states there is still the need for check-in facilities, however technology will provide faster and more efficient ways for checking in baggage.

Three types of assignments can be used for each solution being the costumer the airline who requests it (de Neufville & Odoni 2013): (1) dedicated-use – the facility only provides service for one costumer; (2) flexible-assignment – the facility only serves one costumer at a time but it can be used by several costumers during the day; and (3) common-use – the facility serves multiple costumers anytime.

2.3.2 Check-in developments

To accommodate passenger's needs and the luxuries given to them by the airlines, several solutions have been introduced to perform check-in. Solutions such as e-ticketing and SST put many of the activities needed for the check-in process away from the terminal (Ashford et al. 2011). The following issues are found over the literature (Table 2.4): Optimization of check-in area (Joustra & Van Dijk 2001), passengers behavior towards SSTs (Castillo-Manzano & López-Valpuesta 2013), passenger satisfaction (Wittmer 2011), optimized check-in (Hsu et al. 2012), terminal capacity gains (Kalakou et al. 2014) and shared use facilities (de Neufville & Belin 2002).

Table 2.4 – Check-in research areas.

Author	Field	Optimization	Cost-Reference	Behavioral	SST's
(Joustra & Van Dijk 2001) "Simulation tool box to evaluate operational check-in rules and determine growth capacity."	Common vs Dedicated Use Check-in Counter	X			
(Yan et al. 2004) "Model to assist airport authorities to assign common use check-in counters."	CUCC	X			
(Appelt et al. 2007) "Check-in procedure optimization over a scenario analysis."	Check-in optimization	X			X
(Lu et al. 2009) "Evaluate passengers' intention to use SST and explore the influencing factors."	Acceptance of SSTs			X	X
(Bruno & Genovese 2010) "Optimal number of check-in gates to balance operative costs of service."	Airport Check-in models	X	X		
(Hsu et al. 2012) "Minimize waiting time using a dynamic allocation of check-in facilities"	Dynamic allocation	X			X
(Kalakou et al. 2014) "Assess the impact of forthcoming changes on the airport's departure hall."	Simulation, Innovative technologies	X		X	X
(Mujica Mota 2015) "Determine most efficient facility allocation considering stochastic aspects of the problem."	Simulation	X			
(Martin-Domingo & Martín 2016) "Studies the adoption of mobile internet in airports"	Mobile applications				X

Traditional check-in is categorized into two distinct types, dedicated-use check-in counter and common-use check-in counter (CUCC). Dedicated counters would only serve an airline at a time whilst common use could be used to serve different airlines and flights at the same time (Kazda & Caves 2015). CUCC improve queuing times created by the fluctuation peaks over the day and provides a positive effect for both planning of counters and the personnel planning (Joustra & Van Dijk 2001). When check-in kiosks were first introduced around 20 years ago, they were installed by each airline for their passengers use – called dedicated kiosks. This was a prime advance in SSTs at airports, adapted from others industries where this technology had increased productivity reducing customer waiting times (Peterson 2006). The use of dedicated kiosks was a way for airlines to differentiate themselves creating a competitive advantage. It was expected that an increase use of the kiosk technology would improve efficiency, instead the use of common-use check in counter, one of the slowest processes (Appelt et al. 2007), was proving to be more efficient. Just as Shangyao Yan (2004) concludes the majority of airports were facing a growing number of passengers and, due to a limited number of space the application of common use check-in counters (CUCC) had become more prevalent than it previously was.

There was no uniformity in the kiosk industry and so, investment and maintenance costs proved to be high due to its exclusivity. Liu Changyou et al. (as stated in Jun, 2015) brought the problem to light stating there was an “overlapping investment” leading to mixed self-service services not accomplishing the expected targets i.e. reducing operational costs, queuing time and increasing passengers experience. The introduction of the Common Use Self-Service (CUSS) kiosk was inevitable even though airlines would lose individual influence and control over the process. In terms of the airport design this solution enabled more flexibility allowing terminal space to be used more efficiently. Due to its efficiency, common use kiosks allowed terminals to handle a higher volume of passengers without the necessity of expansion (Graham 2014).

Kiosks serve the passenger by issuing his boarding pass (choosing seat and amenities) and it can print his own baggage tag as well (Graham 2014). Kiosks offer an advanced accelerated process over the check-in integrated with a drop-off counter bringing many advantages, as it saves passengers time and cuts airlines cost. In 2016 91% of the airports worldwide used kiosks to issue the boarding pass and 51% to print the baggage tag (SITA 2016). Being the most used solution at airports, some strategies are being developed to accommodate airports needs for check-in and improve passenger experience with a complete self-service process.

SSTs provide faster and easier check-in for passengers. However, the user perception and acceptance of the SSTs may restrain its potential i.e. the success of implementing SSTs is intimately related with the passengers accepting SSTs. It is risky to assume that a technology will be accepted and used by the users only because of how beneficial it seems to be (Holguín-Veras & Preziosi 2011). Lu (2009) researches passengers’ propensity to use self-check-in services as airlines keep introducing this type of technology finding that airlines should persuade passengers to acquire a more positive attitude towards the check-in kiosks. Many passengers still do not accept and use SST solutions meaning traditional, operated check-in counter procedures remain necessary (Wittmer 2011; Bruno & Genovese 2010). Mobile kiosks provide the same service as a kiosk but can be moved inside the terminal to cater demand during peak fluctuations (Figure 2.8). This service enables flexibility inside the terminal since passengers will spread more evenly over the terminal. Auckland Airport in preparation for a sudden growth proceeded with the installation of 45 mobile self-service kiosks (FutureTravelExperience 2017).

Figure 2.8 - Auckland first mobile self-service check-in. Bates (2017).

Agent Xpress, is a ground agent that performs face-to-face check-in services at any point of the terminal without being tied to a specific check-in counter. It allows the passenger to interact with an agent and alleviates pressure on check-in queues during peak hour. This solution has been used in (KLO) Kalibo airport, Philippines and other Asian airports where face-to-face operation is valued (FutureTravelExperience 2014).

By 2020 IATA predicts 80% of passengers will be assisted by a full self-service check-in process (IATA 2013). By that time kiosks may only be used to print the baggage tag or will cease functions resulting in terminal one-step check-in activity (baggage drop-off only). Drop-off counter is a recent check-in solution, introduced in 2008 at Schiphol International Airport by KLM. It enabled a much smoother passage through the terminal with fewer waiting times for the passenger. When introduced it was an assisted counter, and the process was named ExpressDrop" (ATB). Though it proved to speed up the check-in process it was unable to reduce staff levels (Kazda & Caves 2015). It can be assisted or self-service common-use or dedicated technology.

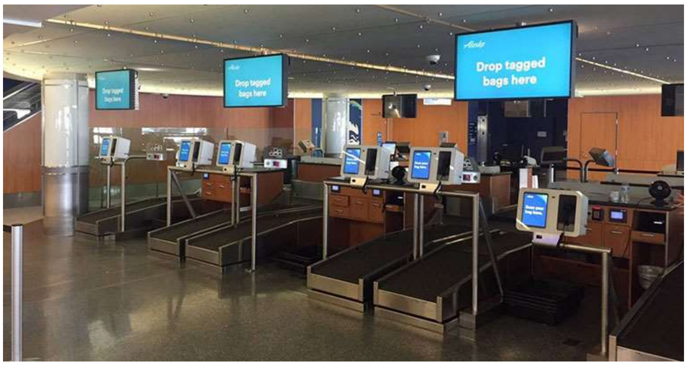


Figure 2.9 - Drop-off counters

Mobile applications are growing in the market enabling users to process many of the check-in tasks remotely. Online check-in issues a boarding pass in paper or electronic form that can be read by a variety of readers. This allowed airlines to reduce operational costs by reducing the required space for check-in (Kalakou et al. 2014). Mobile applications can manage all the check-in process except the baggage processing hence the need for a self-service or assisted drop-off counter. Mobile applications will be considered basic services (Martin-Domingo & Martín 2016).

Ongoing studies refer Near field communication (NFC) as a new technology that will allow faster check-in processes by replacing the physical bar code image (Kalakou 2016). Since 2012, advances in self-service check-in made it possible to print the boarding pass before arriving to the airport resulting in a reduction in the number of counters and airline agents required. Low-cost airlines were the first ones to force passengers to use this check-in solution (Kalakou 2016). With the use of smartphones and internet, the remote methods reduced even more the check-in costs for the airlines. This self-service method creates concern due to its inability to deal with the baggage processing. As Hsu et al. (2012) suggests: even if the passenger has already a printed boarding pass but has to dispatch luggage, a counter is still needed.

Figure 2.10 – Self-tagging technologies.

With the increased use of self-service baggage drop-off counters, home-printed bag tags and reusable electronic bag tags (Figure 2.10) are becoming more and more available and are continuously offered by many airlines. Home-printed bag tags are to be printed at the same time as the boarding pass is. By 2018 more than ¾ of carriers intend to offer this service (Nicas & Shukla 2015). Reusable electronic bag-tags are based on RFID technology which is easily read and enables the information to be reprogramed into the chip. Even if considered a good technology, it is in its pilot stage and creates many overlapping issues. For instance, when the passenger connects to another airline that has not implemented this technology the bag will be physically tagged creating two opposite information.

In summary, the number of current and future developments will produce a more efficient airport. These developments are creating more efficient and easier processes, improving passengers experience and increasing terminal capacity. From the operator's point of view, more terminal capacity might create an overdesigned terminal and consequently new challenges are emerging. The departure hall needs to be studied for new opportunities in terms of layout. It can be an opportunity to increase discretionary revenues. In short, all terminal planning will need to evaluate these changes.

2.4 Modeling for pedestrians

Simulation models replicate the system processes as functions of time using mathematical, logical or numerical models. Simulations are designed to run the model and predict a certain system behavior by estimating the changes in systems over time. The primary advantage of simulation is to present a good representation of a complex system in order to evaluate real-world system behavior and to monitor operational performance without the need to physically create the system (Ashford et al. 2011). As the future is not foreseeable and forecasts are wrong most of the time due to the sensitiveness of all the agents involved, the airport operators need to anticipate a broad range of possible outcomes (Magalhães et al. 2013).

Airports, in specific passenger terminals are complex environments ideal for simulation application: processes are stochastic, in a continuous state of change involving moving and fixed objects (Esteban 2008). Carrying a simulation model over the passenger terminal to assess gains and optimize process has been proving to create major improvements in the terminal area (Table 2.5).

Table 2.5 - Simulation applied over terminal area.

	Field	**Improvements**	**Case study**
Chun & Way (1999)	Check-in counters allocation	Using new Inputs for simulation	Kai-Tak International Airport
Joustra & Van Dijk (2001)	Check-in solutions (CUCC & Dynamic allocation)	Simulation Tool Box	Amsterdam Airport Schiphol
Appelt, Lin & Hall (2007)	Data collection used to build a simulation tool	Deciding nodes for different check-in procedures	Buffalo Niagara International Airport
Bevilacqua & Ciarapica (2010)	Check-in solutions (CUCC vs dedicated)	-	-
Kalakou et al. 2015)	Future terminal solutions (Biometrics & NFC)	An agent-based modeling	Lisbon Humberto Delgado Airport
Zhao, Zheng &Zhang (2015)	Check-in solutions (Kiosk allocation)	-	-
Kim, Kim & Chae (2017)	Baggage handling system	New allocation algorithm for baggage handling system	Gimhae International Airport

Chun & Way (1999) analyzed the check-in counter allocation problem that traditionally had the resource allocation performed manually based on prior experience and simple heuristic. This created the problem of relying on the skill of a human scheduler who, due to the problem's complexity, wouldn't be able to predict accurately on a daily basis. The authors then created an intelligent resource simulation system (IRSS) - a knowledge based simulations - to daily predict the number of check-in counters to allocate to each flight while maintaining sufficient service quality. This simulation inputs include different service rates (destination, airlines and handling agents), different passenger arrival patterns (times of the day and days of the week) and different requirements. The results show that using simulation with resource allocation led to resource savings of up to 40% when applied to Kai-Tak international airport.

Joustra & Van Dijk (2001) gives detailed insights on why simulation is a necessary step to evaluate check-in, referring advantages such as realistically predicting queuing time due to the capacity of modeling with peaks in arrival patterns and the easiness of testing alternative check-in solutions. Using a simulation tool box, two simulation studies where carried over Amsterdam Airport Schiphol. One to simulate several proposed check-in rules: concluding that common-use check-in would bring advantages to operational level, dynamic opening and closing of the counters would reduce queuing times with less operator hours and extension of the check-in period would reduce the opening counter hour passengers peak. Other rules were also applied. The second study was carried to determine the maximum possible growth in the terminal.

Appelt, Lin & Hall (2007) explained the data collection process which improved the simulation model presented. Having different check-in solutions (Express kiosk, kiosk, online counter and curbside) implied that decision process could influence the check-in process thus to model the system it was created decision nodes that would be influenced by the data collected earlier. After different scenarios analysis, the conclusion was that different check-in combinations would best fit under certain scenarios.

Kalakou et al. (2015) proposed to study about future developments in the departure hall. Facing the introduction of disruptive technologies such as the NFC and the usage of biometric data regarding the check-in and the security process, a simulation model was carried out to assess the capacity gains of the terminal. Uncertainty was introduced in the model by diving into three types of passengers (known, normal and enhanced). Both long and short-term scenarios were studied concerning expected technology developments. After the study, the author concluded that biometric system, NFC and smartphones will continuously change facilities and operations in the departure hall. Modern technologies reduce the average time-to-boarding and increase terminal capacity meaning that some airports will need to reconfigure their space, therefore implement flexible designs is a great advantage.

To improve queue imbalances in the terminal area, Kim (2017) developed a new baggage handling algorithm to cope with the issue of linear counter configuration was creating. Due to linear configuration and conveyor running in only one direction when baggage was loaded into the system the conveyor's slot availability depended on the previous counters. There was always an available slot in the beginning of the conveyor and the following counter relied on the slots left from previous counters. This situation created a delay for the last counters reducing the level of service and the customer satisfaction. A simulation was used to verify the feasibility and the improvements achieved by implementing the algorithm. The results indicated that the suggested algorithm reduced the imbalances.

Simulation offers fast, flexible, transparent, animated and accurate tools which help airports test, evaluate and operate new operational solutions. Findings over the literature indicate simulation is used in a broad range of terminal operations, from future developments to evaluating new operational directives. Simulation is preferred to test technologies or solutions that have not yet been physically tested in that environment. Simulation is then a powerful tool that must be used to enhance airport planning.

2.4.1 Pedestrian behavior

Decision-making process of passengers making their way through the airport terminal environment is one concern of this dissertation. Surrounding environment and the system, where the passenger is the main agent, involves plenty of uncertain factors which have impact on passengers' activities. Understanding how people walk has motivated many researches over different fields. Walking behavior may change with distinct categories of passengers. Passengers behave differently in both spatial and temporal aspects according to the purpose of the action, the time of the day, the health and fitness condition, the surrounding people, the gender, the age, the culture, how well the passenger is familiarized with the airport, the effectiveness of the wayfinding guidelines provided and the building environment (Ma 2013). Each passenger has its own traits (e.g. age, gender beliefs, needs, perceptions, etc.) that influence his behavior in terms of activity choice and walking characteristics. Also, interactions with the environment play a major role in terms of the pedestrian choice behavior.

The destination choice problem is tricky in the context of pedestrian behavior. Some individuals may not have a predefined destination. From a procedural point of view, the individual choses his destination based on the activities he wants to perform. Destination selection is then a problem of activity planning and scheduling (Bierlaire et al. 2003). All decision-making process is traditionally distributed along a hierarchical structure. At strategic, tactical and operational level (Figure 2.11), the pedestrian is involved in a destination selection process (Hoogendoorn 2001 according to Dijkstra et al. (2009)).

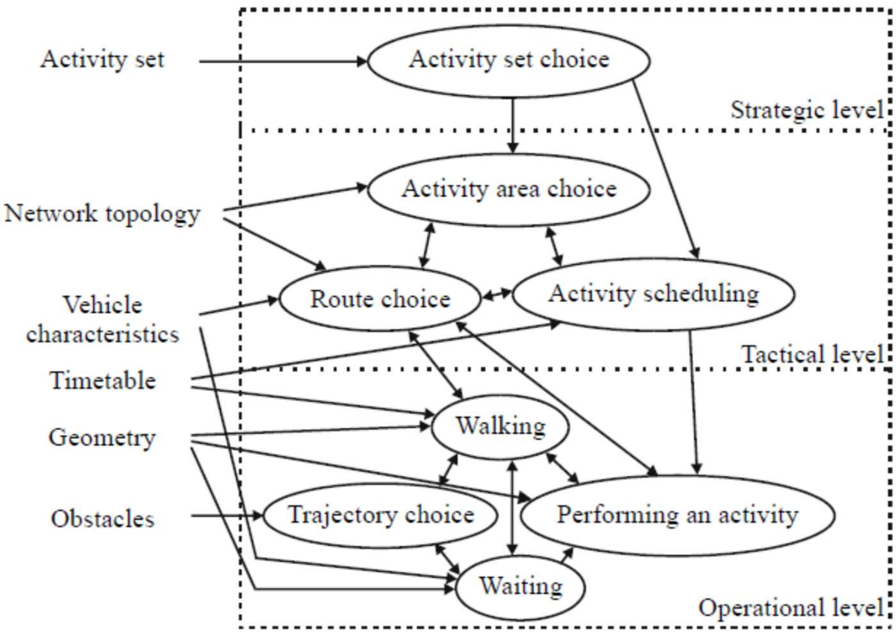


Figure 2.11 - Stimulus leading to changes in pedestrian behavior. Helbing & Molnár (1994).

Passenger target and route choices within an airport terminal are conceptualized as passengers arriving at an entry point and being faced with the problem of choosing from several possible destinations. Route choice itself is explained as a result of a decision-making process through which passengers integrate their utilities. Passengers evaluate each set of choice alternatives with their set of attributes relevant to their decision-making task and chose the alternative with best outcomes (Ma 2013). As an example of activity choice, the passenger could proceed directly to the check-in or decide to linger around shops at the terminal.

Walking behavior: The choice of the next step

The choice of the next step is related with the direction of the walk, as well as the speed. It represents the instantaneous decision and implies a lot of factors. Antonini et al. (2005) proposes a discrete choice modeling combining speed and direction. The choice set is multidimensional, combining three levels of acceleration with 11 possible directions. It must be adapted to the environment and can adapt to pedestrian characteristics such as age, sex, height, visual angle and group formation.

A utility function associated with the given alternatives (location and acceleration), must capture various behavioral patterns. Speed and interaction will be discussed in the following sections. Two patterns can be found: (1) Turner's (2000) angular analysis concludes a body, e.g. a person, will reach their destination turning as little as possible, following smooth and regular paths; and (2) the other concerns attraction of the destination, meaning the pedestrian wants to arrive to its destination as fast as possible. It is possible to conclude that an alternative that leads the pedestrian closer to the objective has higher utility. To shape these patterns, the angle between direction *d* and direction *Dn* is defined as shown in Figure 2.12 (Antonini 2005). The concept of perception is introduced as the pedestrian has a limited range and angle of view. The pedestrian interacts with others within his visual field.

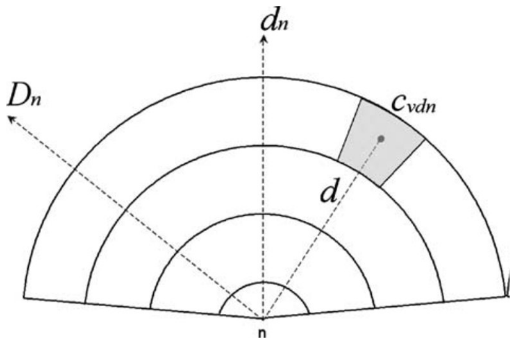


Figure 2.12 - Destination and direction.
Antonini (2005).

Walking behavior: The choice of speed

Speed choice can be perceived into two separate ways. It is either considered integrated within the "next step" model – explained above - or it can be considered as a choice of speed independent from other walking decisions. Commonly, in both there are two possibilities to address the choice of speed: (1) It can be a list of possible speeds, from zero to the maximum speed, applied to different states; or (2) a different range of possible modifications to the current speed, relative (e.g.+10%) or absolute (e.g. +0.1m/s). Relative increase creates a more natural system, but it must integrate some form of avoiding unrealistic variations in speed (Bierlaire & Robin 2009). Many variables may explain the speed behavior and must be included in the model specification. Density and flow, or a combination of both results in different speed for pedestrians.

Seyfried et al. (2005) analyzed the relation between density and velocity of pedestrians, concluding the speed of the pedestrian would decrease in the presence of medium or high densities (Figure 2.13). The environment a pedestrian is walking in has an impact in the speed choice process. Walking speed behavior has aroused some research over transportation systems, in special but not only, about walking speeds of pedestrians within airport terminals. Young (1999) found lack of research on the field of walking speed inside terminals thus analyzed pedestrian walking speed when affected by the use of moving walkways. His findings pointed to no variation in the mean walking speed of the pedestrian inside the airport from pedestrians in other transport systems.

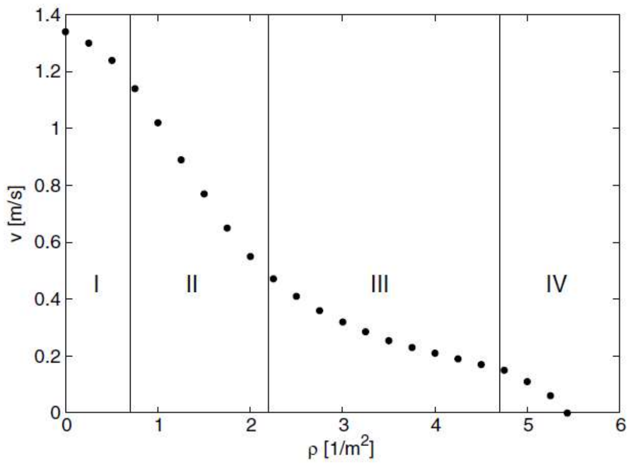


Figure 2.13 - Relation between density and velocity.
Seyfried et al. (2005).

Schultz et al. (2008) after investigations at Dresden Airport, points out that the passenger speed at airport terminals is related to the age of the passenger, travel purpose, group size and the amount of baggage the passenger is carrying (Figure 2.14). Other factors mentioned but not included in the study are interactions with other passengers (density/velocity), approaching intersections (passengers would decelerate due to the lack of field vision) or gathering information (either by stopping at information panels or decelerate to check signaling).

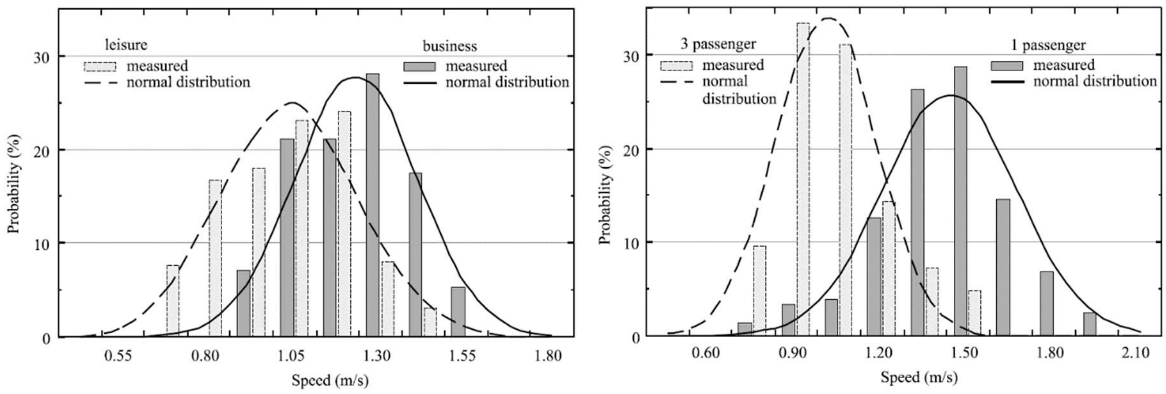


Figure 2.14 - Trip purpose and group size influence on walking speed. Schultz et al. (2008)

Interactions

Interactions between pedestrians and the surroundings, both other pedestrians or the environment, are as important as other aspects when analyzing their behavior. First, there is the group behavior, in accordance to what was presented before, a group of pedestrians will walk at a different speed, and different formation than when walking alone. Second, the complex organization of crowds, that includes principles of density/velocity behavior, leader/follower behavior and collision avoidance behavior. And thirdly the interactions with the environment which enables the pedestrian to be attracted or repulsed by objects within its visual field (Bierlaire & Robin 2009).

Group behavior and organization of crowds relates to the adjustment to the surrounding pedestrians. It can be motivated by social links, friends, family or occasional proximity, or by behavioral affinities (eg. fast people passing slower individuals in a dense crowd). Over the literature, there is research on how individual decisions may be influenced by other members of the group, group sizes and group formations (Bierlaire & Robin 2009). Leader-follower is a principle that captures the propensity of an individual to adjust his course and speed to another individual, the leader, to make his way through the crowd. This is an unconscious behavior (decide or not to follow an individual) and the principle is to choose the pedestrian who has a similar speed and walks closely to the desired direction. Collision avoidance is the behavior of being repelled by the other pedestrians. Under distinct situations (density, velocity, etc.) the pedestrian may have various levels of collision avoidance.

While pedestrians are walking, several scene elements emerge, creating the need of interaction between them. Scene elements are physical objects such as cars, shops, obstacles, walls, signaling, etc. Interaction can only occur with an object in the pedestrian range. These interactions need to be distinguished between what elements influence the behavior and how (Bierlaire & Robin 2009). Dijkstra et al. (2009) distinguishes activities as impulsive and non-impulsive. Impulsive activities result from an interaction with the environment according to a framework (Figure 2.15). Perceiving the environment may include actions such as slowing down to have higher degree of perception, stopping in front of an object to have better insights or simply ignore it.

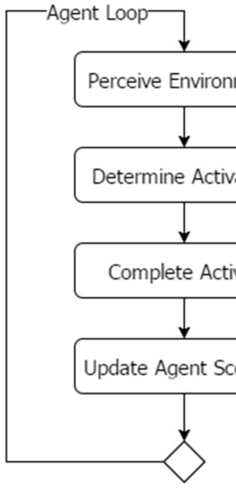


Figure 2.15 - Environment interactions.
Dijkstra et al. (2009).

Bierlaire & Robin (2009) suggests interaction with other elements, not only pedestrians, should be included on the choice of the next step in order to best replicate the walking behavior. The same author explains pedestrians usually anticipate interactions by slowing down or adjusting their walking direction. Many objects emerge inside an airport terminal create interactions between the pedestrian, in this case the passenger, and the object itself. Signaling, different types of stores and different types of facilities create many opportunities for interactions (Ma 2013).

2.4.2 Pedestrian modeling

Development of transportation systems motivated important research activities in the context of behavioral dynamics with the creation of new models (driving and travel behavior models), new simulators (traffic simulators) and new integrated systems to manage various elements of intelligent transportations systems (Antonini 2005). Several models of pedestrian movement have been developed since the 1990s. A type of pedestrian model is derived in analogy to fluid dynamics and particle systems but also shows ideas originating from the theory of self-organization (Dijkstra et al. 2009).

Crowds have been studied as a self-organizing phenomenon (Helbing & Molnár 1994) and self-organizing pedestrian movement (Helbing et al. 2001). Events, such as evacuation and escape situations are the main focus of some models. Other types of models have been suggested: pedestrian following models, pedestrian dynamics, behavioral models and pedestrian flows (Dijkstra et al. 2009).

Traditional modelling approaches were meant to address a single specific issue. New pedestrian models have the tendency to combine multiple traditional modelling approaches (Zheng et al. 2009). Some of these models involve agent-based modeling, reflecting the interest in multi-agent models. This type of model captures the decision making at the agent level thus creating a more realistic expression of human behavior.

Evacuation models

Selection of the exit route is one of the most crucial decision that pedestrians face in emergency situations. These models have aroused motivation over the literature for safety reasons. They provide information for building design, and are designed to determine exit preferences and pedestrian desired routes, or to ensure proper available area to enable a secure evacuation. These models are applied to various areas such as: buildings, underground spaces, passenger trains, railway stations and airports (e.g. Klingsch et al. 2009)

The studies are used to test buildings response to emergency designs, measure efficiency and space availability to provide a smooth transition for the evacuation. These models provide insights about which exits may be preferred by pedestrians, how pedestrians will proceed towards their desired exits, points in space that create bottlenecks and designs that allow a better pedestrian flow towards their desired objective.

Behavioral models

To accurately represent a pedestrian a behavioral model is required. Although pedestrian modeling requires advanced understanding of the human behavior, some behavioral aspects could be considered to realistically represent the pedestrian (Koh & Zhou 2011). Some models represent behavioral changes including interactions with other pedestrians. Helbing & Molnár (1994) introduced, in the social-force model, an acceleration or deceleration as a reaction to external information. The model included factors dependent in crowd-density, distance from borders and attractive effect among pedestrians and places or objects.

Pedestrian flows

In contrast to previous models, pedestrian flow models represent pedestrian movements at a macroscopic level and these models can accurately represent the pedestrians as a group rather than individually. Understanding the behavior of a pedestrian group is a complex process due to the complex nature of human beings (Kalakou 2016). Pedestrian flow models represent the pedestrian interactions with the environment's objects and other pedestrians and can be used within airport terminal.

2.4.3 Agent-based models

Agent-based modelling (ABM) offers a way to model complex systems that are composed of agents who interact and influence each other, learn from their experiences and adapt their behavior so it is better suited for complex environments (Ma 2013). It is a relatively new approach to modelling systems formed by autonomous decision-making agents. Agent-based models, by simulating interactions between individual agents, are built from 'bottom-up' (Macal & North 2014). Agent-based models represent some pre-determined rules of behavior that allows the agent to execute and perform activities in the environment system. This advantages make ABM suitable for the study of pedestrians in complex environments such as airports (Lin 2014).

Bonabeau (2002) mentioned how ABM has been seen in the real-world business problems and presented an introduction to the principles behind ABM for simulating human systems. The author states three benefits of ABM over other modeling techniques: "(1) ABM captures emergent phenomena; (2) ABM provides natural description of a system; and (3) ABM is flexible”. Furthermore, Bonabeau (2002) mentions an agent-based simulation as a mindset other than a technology. To support his conclusions, the author presented several examples where ABM is applied: traffic and pedestrian flow, market and organizations. The conclusion that ABM can bring benefits when simulating human systems is accompanied with the warning that ABM are conceptually deep and need a lot of information to be built. Macal & North (2014) present a tutorial on agent-based modeling, the authors illustrate the theory and foundation of ABM. It is suggested by the same authors that a typical agent-based model is formed by three components (Figure 2.16):

1. Agents: a set of agents, characterized by their attributes and behaviors.
2. Agents interactions: agent relationships and methods of interaction.
3. The environment: environment where the agent is placed and the relations between agents and environment.

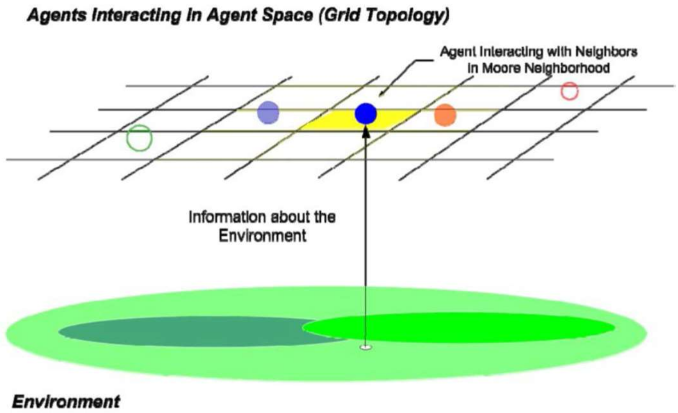


Figure 2.16 - Structure of a typical agent-based model. Epstein and Axtell (1996).

At airport level, studies seem to be done at aggregate level and not incorporate the individual itself. Ma (2013) acknowledge that airport simulation mostly focuses on airport standard processing procedures resulting in a non-explanation of the formation of movement flows. Therefore, the author proposes a ABM to evaluate how cognitive factors of the passenger affect movements in an airport terminal. By introducing discretionary activities and passengers’ characteristics the model would provide more intuitive results in passenger flows. The author simplified passenger characteristics into aggregate traits to simplify the model. In the end, a simulation was conducted proving that passenger flow was indeed more intuitive and natural when including discretionary activities and passenger characteristics.

In addition Lin (2014) developed an agent-based model to represent pedestrian flows inside an airport terminal. The model included the effect of group dynamics in pedestrian flow. The development of the model included group characteristics such as velocity, group formation and group interaction with the facilities. A passenger flow model simulation was performed to assess variations in the performance and utilization of services in an airport terminal and then followed by an evacuation performance assessment. Groups dynamic changed how crowds move through the terminal, the author concludes the impact of group dynamics during an airport evacuation process significantly change evacuation process.

Agent-based models provide understanding on the operation of a complex environment by representing agents based on pre-determined behavior and local interactions. Representing human behavior includes many soft and unpredictable factors which are of complex representation and quantification, resulting in a difficult calibration. Further on, agent-based models found in the literature are not fully documented which represent a difficulty for others to reproduce the same results (Lin 2014). Bonabeau (2002) suggest some consequences emerge on the level of trustworthiness of the results of an agent-based model from the lack of detailed information. In addition, the same author refers quantitative results of the simulation should be interpreted only at the qualitative level. Agent-based models result in more computationally expensive models than others, thus modeling large and complex systems is still a challenge for agent-based models.

2.5 Chapter review

Airports are complex systems in which the pedestrian faces the most relevant figure. When using the airport terminal, the pedestrian needs to perform all the aeronautical activities and some discretionary activities also. Literature suggests how discretionary activities have impact on airport operation and are one source of income to the airport itself. When studying the check-in process there are several options to perform check-in and more advanced solutions start to emerge in the market creating a lot of opportunities for the traveler.

Check-in process is changing rapidly, and terminals need to adapt to these changes. The introduction of emerging technologies such as fully automated check-in counters (self-service drop-off) is changing the check-in paradigm while biometrics and NFC are being tested to enhance security and to speed all the process. Yet these introductions should be done gradually to let passengers adapt. Passengers profiles inside the airport exist, and each profile reacts differently when presented with more advanced check-in solutions.

Conducting simulations is the preferable way to test some hypothesis by creating some scenarios and running them in the simulated word. Literature shows that little to no emphasis is given to the pedestrian characteristic when simulating an airport terminal.

Pedestrian flow is gaining ground in the world of modeling, especially in complex systems that evolve many agents. Airport terminals are a good environment to perform a pedestrian flow simulation. Agent-based models are the best suited for represent the pedestrians inside an airport system. Several models and simulation tools exist to study flows of people inside complex areas, yet the focus is on the pedestrian's behavior regarding the navigation. Interactions are only considered as a set of objects to avoid while moving. Some authors refer the need to introduce interaction with all the surrounding environments, creating impulsive and non-impulsive activity choices.

Chapter 3 – **Developing an agent-based model**

This chapter presents principles used in the creation of the agent-based model meant to represent pedestrians' process inside terminal. Starting by explaining the structure of the ABM and then, the creation of the model for an airport terminal. All model components: (1) agent; (2) environment; and (3) interactions; are approached and studied accordingly. After, the model will be implemented in the simulation tool and the simulation model structure will be reviewed. The model can be accessed here: https://1drv.ms/f/s!Ar3wNc95diY3zlgtQOifKe0gV5uv

3.1 Agent-based model structure

In an agent-based model, the three key elements that need to be identified and modelled are: agents, agent's environment and both interactions between agents and between agents and the environment (Figure 3.1) (Lin 2014). Model is focused on representing the passengers' process inside the airport terminal, in specific on the landside area of the terminal. Understanding passenger's activities inside the terminal is a crucial step to build the model.

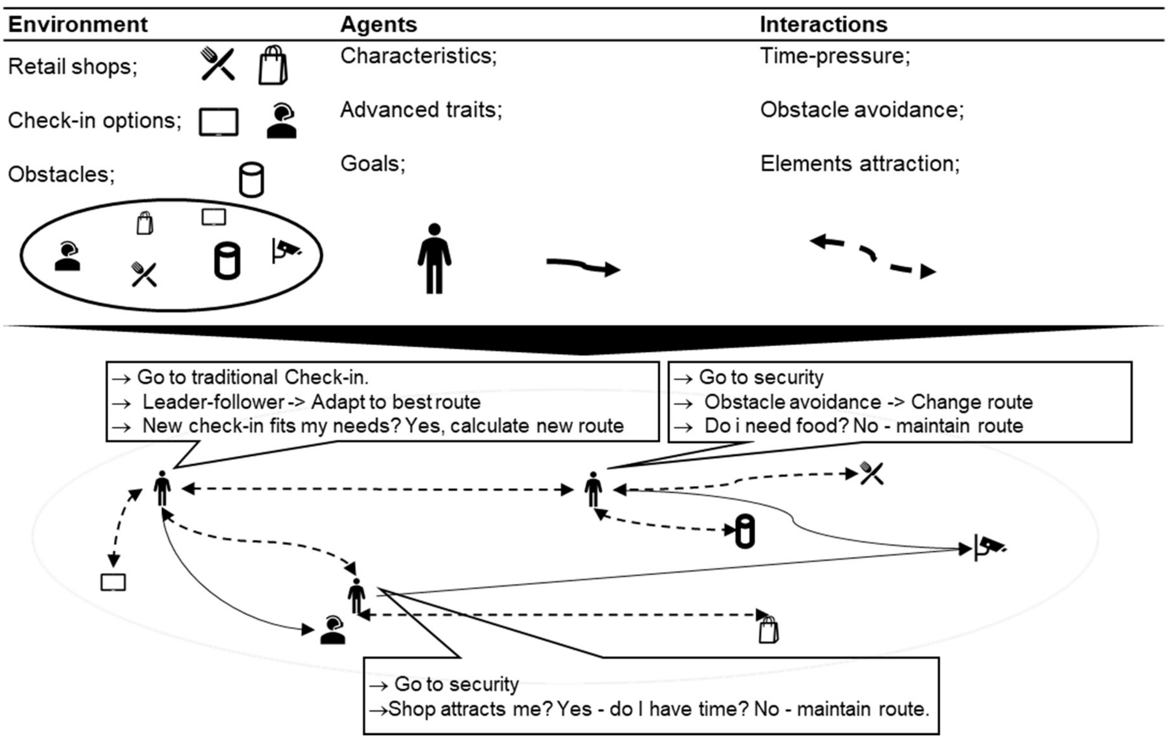


Figure 3.1 - Schematic of agent-based model

Passengers' goal is to complete all aeronautical task, but he may also perform other type of activities to accommodate other needs. There should be an understanding of all possible alternatives for the pedestrian to reach security and then proceed to articulate them. Aeronautical processes are the main purpose of using the terminal. The check-in process is the only aeronautical process on the landside terminal area therefore there should be a good representation of it (Figure 3.2). Yet, discretionary activities must be included in the passenger's agenda to fulfill other needs

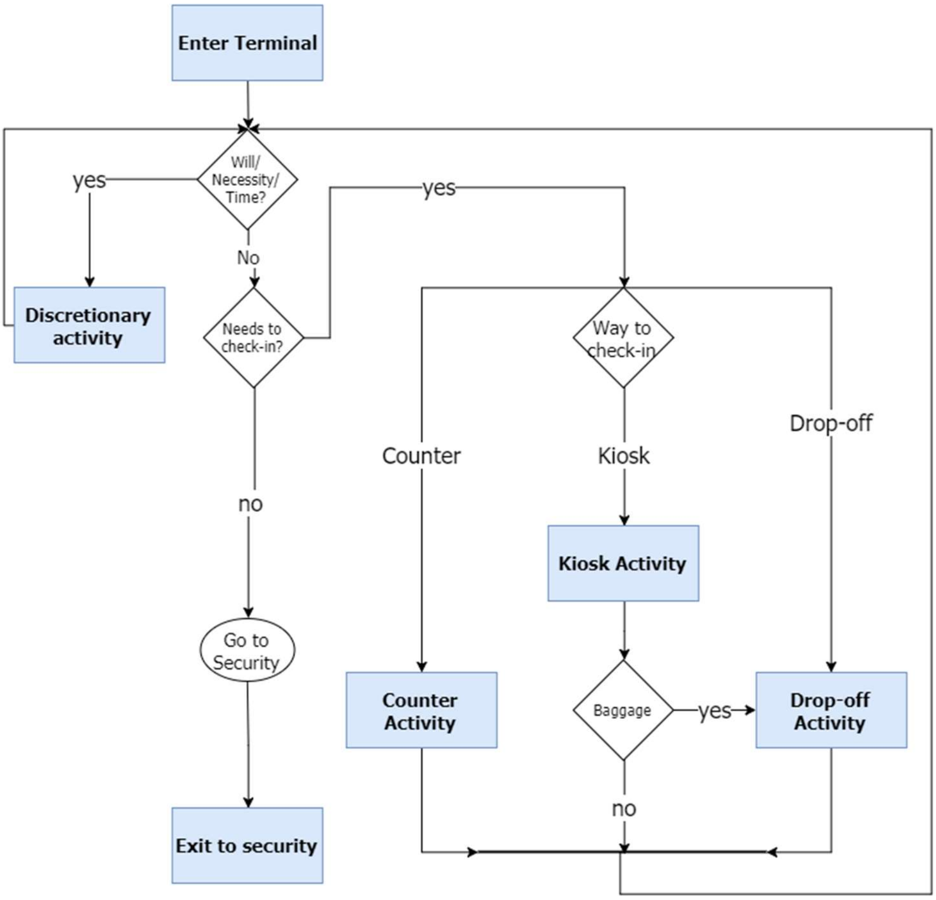


Figure 3.2 – Passengers' activity diagram.

Check-in

Being the most important sub process of the terminal's landside process, it must be defined in terms of solutions and dwell times[2] to have a further insight about the queue times. Figure 3.2 shows how check-in process is included in the passenger's diagram. Many solutions are offered by the airlines to perform check-in activities. Some solutions do not even require any aeronautical procedure inside the terminal's landside area (e.g. online check-in). The type of check-in depends on passengers' characteristics and needs (Castillo-Manzano & López-Valpuesta 2013) i.e. if a passenger is comfortable with technology, the passenger prefers a self-service solution to check-in the baggage.

Each check-in solution can serve various purposes, hence the time spent at each facility depends not only on the type of facility itself but also on the passenger requirements (Table 3.1). The passenger may need from the check-in area: (1) boarding pass; (2) dispatch hold baggage; (3) both; and (4) nothing. The choice is related to his characteristics and needs, but also with interactions that may occur.

[2] Total time the passenger spends inside the terminal (Lin 2014).

Table 3.1 – Average processing times check-in facilities. ACRP (2008).

Check-in facility	Requirements		Processing Time [sec]
Counter			204 +- 20
	Print + apply bag-tag	**Drop baggage**	
Self-service drop-off counter[3]	X	X	65 / 30 +- 5
	-	X	40 / 20 +- 5
Assisted bag-drop counter	-	X	80 +- 20
	X	X	95 +- 20
	Print Boarding	**Print bag-tag**	
Kiosk*	X		65 +- 20
		X	45 +- 20
	X	X	65 +- 20

*Estimations from self-service drop-off counter.

Each airport will provide facilities – counters; for airlines to provide check-in. Those are requested by airlines, creating a schedule for the counters. Each counter can be: (1) dedicated – serving one airline in his schedule; (2) common-use – serving multiple airlines at the same time; and (3) flexible schedule – serving multiple airlines throughout his schedule without overlapping. Check-in assignment rules will not be addressed in this dissertation as it depends on the airline strategy (de Neufville & Odoni 2013). However, the set of rules applied to the model regarding check-in assignment are as follow:

- A check-in schedule must be provided;
- Check-in counters open 2,5 hours before flight departure;
- Check-in counters close 30 minutes to flight departure, Schengen or non-Schengen;
- Each counter may open or close at any time according to his schedule;
- Each counter can be common-use counter or not according to his schedule;
- Each counter can be fully automated or not;
- Airlines may request a group or single counters;
- Each group or single counter has its own serpentine queue; and
- Kiosks and fully automated counters provide continuous service for specific airlines;

Discretionary activities

Discretionary activities may distract the pedestrian from the main objective. Based on passengers' characteristics, interactions and time stress the passenger may perform some activities on his stay at the terminal. The set of discretionary activities may vary from airport to airport, and many activities can be found at the terminal landside. Such activities include: beverage, retail, info points, ATM, lounge and WC. Recently other set of activities can be found:

[3] Retrieved from Hellemons & Rasmussen (2011), information regarding non-frequent flyers and frequent flyers at Amsterdam Airport Schiphol.

gardens and concerts for example. The time spent to undertake discretionary activities is not always the same (Table 3.2). The author acknowledges passenger characteristics may influence the time spent, yet the model does not take them into account.

Table 3.2 - Dwell time distribution for airport discretionary activities. Ma (2013).

Activity	**Minimum [min]**	**Maximum [min]**	**Distribution**
Food	27.50	29.17	Normal, mean = 28.48
Beverage	3.00	15.00	Normal, mean = 7.35
Retail	5.00	7.50	Normal, mean = 6.18
Info point	0.25	0.50	Uniform
Airline Services	5.00	15.00	Uniform
ATM	1.00	1.17	Uniform
Make a phone call	1.00	5.00	Uniform
Restroom	2.67	3.83	Uniform

Discretionary activities can occur at any time by any user at the terminal, in the departure terminal they occur before security in two preferential intervals (1) from entering the terminal to start check-in and (2) after finish check-in, before start security procedure. Whether a passenger performs or not an activity may vary from time stress i.e. passengers who arrive prior to check-in opening have higher probability to perform any activity; and passenger characteristics i.e. passengers with higher desire to shop have higher probability to perform an activity; and interactions i.e. passengers walking by a shop have higher probability of engaging the activity. Understanding how these factors affect the activity choice is discussed in the next two sections.

3.2 Agent: The airport's passengers

Airport passengers are the main agents in the model. Therefore, first, one must be defined their main characteristics, that will then translate into behavior inside the terminal. Each airport passenger has their own personal characteristics which lead to different behavior and activity choices while inside airport terminal. Basic traits are social-economic related factors (e.g. age, gender, level of education and economic situation) and advanced characteristics as psychological related factors (e.g. eagerness to shop, comfort with technology and willingness to ask for help) (Figure 3.3). To develop an ABM, these factors need to be considered. Due to limited research on how basic traits influence advanced characteristics, the data used in the model is according to Ma (2013) which used a Bayesian network to build his model. His own set of rules has some sort of limitations, for instances, missing some sort of economic influence on eagerness to shop.

Eagerness to shop, level of hunger and comfort with technology are advanced characteristics that will influence the decisions in the present model. Eagerness to shop and comfort with technology are static variables assigned according basic traits. Level of hunger is a dynamic value which increases while staying in the airport, yet it reaches zero if the passenger engages a food/beverage cafe or restaurant. The starting point of hunger level depends on the period of the day the agent arrives. Two thresholds are presented: (1) meal periods: from 8:00 to 10:00, 12:00 to 14:00 and 20:00 to 22:00 (2) other day periods. How basic traits influence passengers' advanced characteristics (eagerness to shop, level of hunger and comfort with technology) is shown in APPENDIX PARAMETERS FOR SIMULATION.

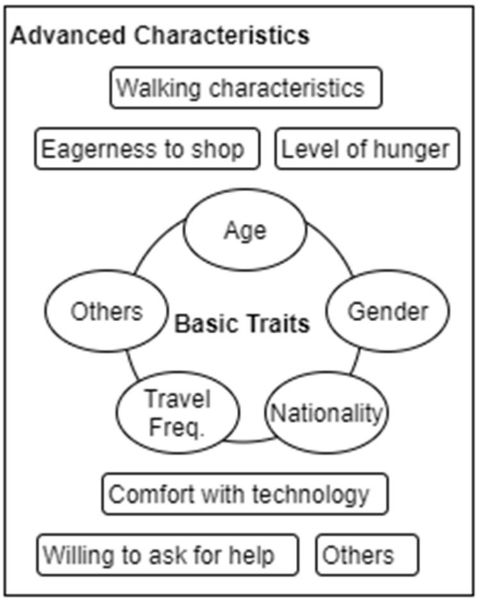


Figure 3.3 - Relation between basic traits and passenger characteristics Ma (2013).

When the passenger enters the terminal according to his characteristics will define the next activity to move to, if check-in facilities are needed in order to proceed to security, the passenger will find some sort of info sign and proceed to the designated counter. In the meantime, the passenger may or may not, perceive other ways to process the check-in (explained in interactions) and after completed all the aeronautical duties on the landside, the passenger will then decide whether to perform some non-aeronautical activities or not, before reaching security.

Passengers' activity choice

When entering the terminal, passengers have to choose from a range of activities, the decision level used in the model is divided into two levels: non-impulsive and impulsive (Table 3.3) (Dijkstra et al. 2009). Non-impulsive choices are made at the strategic level of the passenger behavior while impulsive choices at the operational level. Non-impulsive activities are function of advanced traits and time stress on the other hand, impulsive activities are function of attractions and will be addressed in a further section.

Table 3.3 - Impulsive and non-impulsive activities

Level		Question	Basic traits		Advanced characteristics
1st level	Non-impulsive activities	Which check-in method?	Age; Airline; travel frequency; travel class.		Eagerness to shop; Level of hunger; Comfort with technology; Time stress. Interaction characteristics: Store in range; Store size; Product; Density; Check-in alternative in range; Counter queue size;
		Directly to check-in?	Age; Gender; Travel frequency; Time stress.		
		Activity before security?	Age; Gender; Travel frequency; Time stress.		
2nd level	Impulsive activities	This DA attracts the agent?	Shop size; Product; People inside; Localization.	Basic traits; Time stress.	
		This check-in method attracts the agent?	Queue size; Localization.	Basic traits; Time stress.	

In case a passenger does not need to use any check-in facility he must only decide whether to perform any activity before security or not. However, if the passenger needs check-in facilities he will have to decide three things:

- Which check-in method to use?
- Go directly to check-in? and
- Perform any activity before security?

Choices made inside the terminal are affected by time stress created by the flight departure schedule. Even though people have higher desire to shop or higher level of hunger, their decision is highly affected by the time that remains to perform the next aeronautical activity. Therefore, decision to perform or not a discretionary activity is represented in Figure 3.4 with time stress influence. By introducing time pressure variable suggested by Kalakou et al. (2014), the agent determines if it is preferable to engage the next aeronautical activity or to perform any discretionary activity. Each time representation has two thresholds ***t1*** and ***t2***, one representing the beginning in which time pressure starts to decrease the probability of performing a discretionary activity and the other representing the maximum time pressure a passenger will accept. If the passenger has not performed check-in, those thresholds are: (***t1***) the counter's opening hour (150 minutes to flight departure); and (***t2***) 30 minutes before closing check-in (90 minutes to flight departure). If the passenger has already performed the check-in these thresholds will be 90 and 30 minutes to flight departure respectively.

Figure 3.4 – Engaging a DA probability.

Table 3.4 - Table of probabilities according to advanced traits. Lin (2014).

Eagerness to shop	P1 (retail)	Level of hunger	P1 (food & beverage)
1	6%	1	20%
2	8%	2	22%
3	10%	3	24%
4	12%	4	25%
5	14%	5	30%

Although this set of logic is not all inclusive and needs to be improved and better calibrated, it is sufficient when validating passenger characteristics and choices under time stress conditions.

The choice of the check-in method is related to the advanced traits of the passenger, to the offer inside the terminal and to the airline demands. Today 80% of passengers need to check one luggage (SITA 2017). Passenger who has no hold baggage will not need any check-in device inside the terminal as it is believed he already checked-in online or via app. For the others, the preferred device to obtain boarding pass according to their comfort with technology is presented in Table 3.5. Note that passengers who use web check-in may also use the kiosk to obtain their bag tag depending on the airlines' offer.

Table 3.5 - Check-in method by comfort with technology. ACRP (2008).

	With check baggage	
CWT	Web/app	Kiosk
0	0%	0%
1	21%	17%
4	85%	70%

** CWT - Comfort with technology.*

Passengers' arrival in the airport

Passengers' arrival patterns are not continuous in time and can be influenced by several factors that this model will not represent. The most critical influences of the passenger arrival time at an airport is the flight schedule which must be provided by the airport. The flight schedule contains data regarding flight number, destination, aircraft type and scheduled departure time. For every flight, there will be economy and business seats and each agent will be assigned a travel class.

Passenger arrival has shown some consistent patterns for a single flight, depending mostly on flight type and destination. Ashford et al. (2011) provided an example of arrival pattern of accumulative passenger arrival before Schedule Time of Departure (STD) at a typical European airport as can be seen in Figure 3.5.

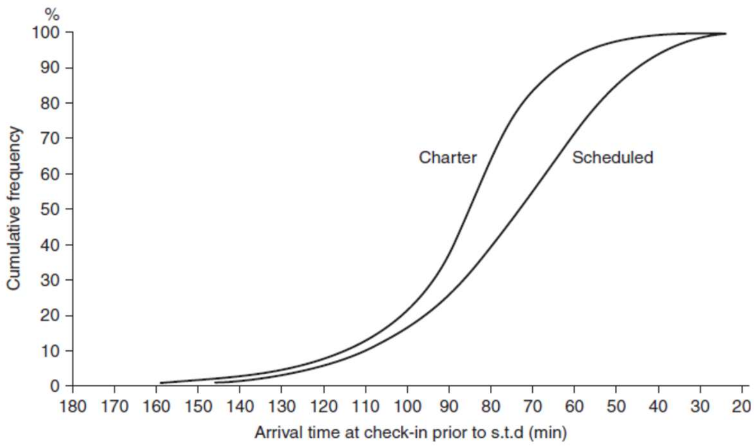


Figure 3.5 - Example of relationship of arrival time for enplaning passengers and type of flight. Ashford et al. (2011)

Arrival patterns are influenced by many factors such as, period of the day, airport accessibility, public transportation and traffic situation. Each airport will show different arrival patterns. Though, common patterns are found throughout airports in Europe (Ashford et al. 2011): (1) The majority of passengers arrived 60 minutes before STD; (2) charter and leisure passengers arrive sooner than business passengers; (3) there is an arrival peak usually situated 100 to 120 minutes before STD; and (4) peak hour in the morning is busier compared with the afternoon and evening peak hour.

Walking characteristics

Previous research has shown characteristics that affect passengers' walking speed in airport terminals. Walking speed can be influenced by basic characteristics of the passenger such as age, gender and travel purpose. Baggage did not influence walking speed since most bags used nowadays are trolleys (Schultz et al. 2008). Influence of basic characteristics in walking speed, the procedure to determine the speed of the passenger is in accordance with Lin (2014):

1. Using Table 3.6 calculate each velocity under each characteristic.
2. The pedestrian speed is initialized as the average speed of the separate values.

$$\bar{v} = average\ (v_{gender}, v_{age}, v_{purpose}) \qquad 3.1$$

$$\sigma = \sqrt{\sigma_{gender}^2 + \sigma_{age}^2 + \sigma_{purpose}^2} \qquad 3.2$$

Table 3.6 - Influence of age, gender and travel purpose on walking speed.

Factor	Source	Value	Mean speed [$m.s^{-1}$]	Standard deviation
Age	(FINNIS K & WALTON 2007)	15<age<30	1.46	0.22
		30<age<55	1.49	0.23
		Age>55	1.37	0.28
Gender	(Schultz et al. 2008)	Male	1.40	0.22
		Female	1.27	0.22
Travel Purpose	(Schultz et al. 2008)	Business	1.36	0.22
		Leisure	1.00	0.23

3.3 Environment: an airport terminal

The model is built to fit the landside of an airport terminal (Figure 3.6). Therefore, the agent's environment are physical components existing in the landside terminal. Each terminal has different layout and configuration yet, the components find in the landside terminal are: (1) aeronautical facilities (e.g. check-in counters and kiosks); (2) non-aeronautical facilities (e.g. stores, restaurants and cafes and other services); and (3) the structural components (e.g. walls, doors and obstacles).

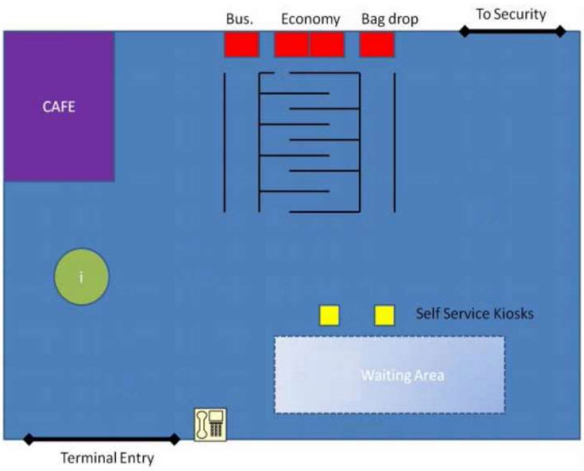


Figure 3.6 - Hypothetical agent's environment.
Ma (2013).

This environment is not fixed for the model, each airport has distinct building design, thus the need to find an existing terminal to apply the model.

3.4 Interactions

When pedestrians face a certain environment, the decision-making process has three levels(Helbing & Molnár 1994): (1) strategic; (2) tactical; and (3) operational. Operational decisions are the last to be made and represent slight adaptations to achieve the tactical decision, such as walking speed or instant walking direction. These decisions come not only with personal characteristics but also with interactions with other pedestrians and also with the environment (Helbing & Molnár 1994). While most interactions do not interfere with strategic and tactical decisions, Dijkstra et al. (2009) explains how interactions can affect strategic and tactical decisions in what it is defined as impulsive activities.

Pedestrian in the airport are driven by a specific goal: complete the aeronautical processes to board the plane, yet they are also faced with other type of non-aeronautical activities. This means our model will introduce distinct types of decisions based on pedestrian characteristics and based on interactions: (1) non-impulsive choices; and (2) impulsive choices.

When entering the terminal, the pedestrian is faced with a complex environment that presents a lot of opportunities to interact, consequently the pedestrian needs to find his way through the airport, where there are stores, cafes, restaurants and service providers that offer several types of goods and advanced technological solutions may be offered to provide a better stay in the terminal.

The pedestrian interaction is a three-step framework of considered behavioral principles (Dijkstra et al. 2009):

1. Perceive environment – The passenger evaluates his surroundings;
2. Determine activation – The passenger, according to the evaluation and his characteristics will determine if is going to change the last decision; and
3. Complete activity – If activated the pedestrian will proceed accordingly.

The model will focus on representing these interactions introducing more decisions at the operational level behavior in the agent. Although this logic can be validated resulting in a better representation of reality and therefore more accurate results, calibration and correct understanding of human behavior is needed. Many factors are not introduced in what is considered latent behavior. This is a complex subject and this dissertation won't be addressing this issue in detail.

Interaction with signals

Wayfinding is the process of finding directions to arrive a certain destination point inside the built environment (Fewings 2001). While walking inside the terminal, one can find, information points, fixed signaling and interactive signaling. The passenger must find his way through the terminal by information gathered from those signals. Info points are distributed among the terminal. However, interactive source of information such as digital screens contain information to where the passenger should proceed. When the passenger enters the terminal, and needs to use check-in facilities he will first locate a source of information, gather the information provided and then decide what activity to choose next.

Interaction with service providers

Service providers (e.g. fashion stores, restaurants and retail) appear while agents move through the terminal creating interaction between both. As stated before, passengers in an airport terminal are mostly goal oriented, meaning the objective is always to catch the plane on time. This highlights the fact that interactions between stores facilities and passenger are of great relevance. When modeling, the fact that a passenger has at his range a service provider that may induce an action (impulsive activity) must be included to best represent the reality.

How to recreate this feature will be explained in the simulation model section, yet the principle is to have an agent always evaluating his surroundings and instantly returning a response, whether to engage the provider or not. Interactions with service providers will always be a function of advanced traits of the agent and providers characteristics. Being providers characteristics the ones referred in Dijkstra et al. (2009): (1) store category (2) motivational state – a pedestrian with leisure purpose has more chances in being activated by a store; (3) Familiarity with the store; (4) store characteristics; (5) basic traits; and (6) time pressure. As remarked by the author these behavioral principles are hard to calibrate and heavy when modeled, therefore a simplification for this issue is proposed, based on eagerness to shop, time pressure and store occupancy.

Figure 3.7 and Table 3.7 shows the two projections of the interaction surface and how these factors may or not affect engaging the activity.

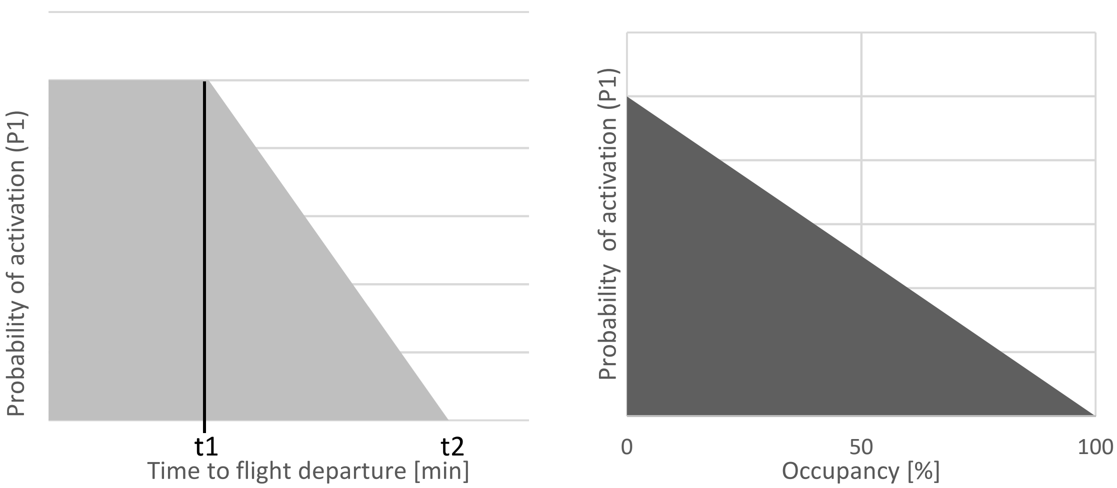


Figure 3.7 - Activation function of time pressure and occupancy.

Table 3.7 - Probability for discretionary activities.

Eagerness to shop	P1 (retail)	Level of hunger	P1 (food & beverage)
1	6%	1	20%
2	8%	2	22%
3	10%	3	24%
4	12%	4	25%
5	14%	5	30%

By introducing these rules, agents will then define the procedure, either stop and proceed to the activity or simply ignore it.

Interaction with other check-in methods

The same principle is applied to other check-in methods that may be presented to the passenger while on the terminal. Currently, passengers may choose between online check-in or counter check.in, yet other methods are already in use and some will be introduced in future terminals. Passengers then, may or may not be familiarized with the new check-in method and may interact with them, creating a reaction that may affect the first decision. Data collected from Castillo-Manzano & López-Valpuesta (2013) concludes that the factors that affect the passengers when exchanging to a new check-in method are: (1) queue size – passengers perceive time as a valuable factor, the smaller the queue the preferable; and (2) comfort with technology – millennials seem to adopt new technologies faster, while older people seem to prefer traditional methods.

Activation level that is affected by comfort with technology (P1 function of comfort with technology) is target of analysis in the present dissertation therefore, the only *a priori* assumption is regarding the passenger acceptance for queues: the passenger will accept a maximum of 3 people waiting per service provider of the new device.

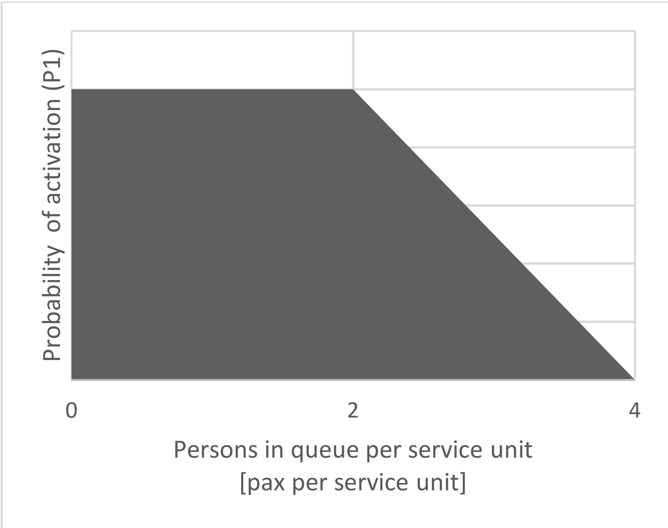


Figure 3.8 - Activation probability (queue size).

Interactions are of immense importance when introducing new technologies and interactions, how people perceive and accept them may be the success or not of their implementation (Wittmer 2011). Adding the fact that modern technologies seem to improve the terminal operational performance, it is of foremost importance that passengers adopt newer methods when introduced to them. Although surveys point the preference for self-service devices (SITA 2017) introduction of new elements should be done in phases, to enable the adaptation of passengers.

3.5 Simulation model

After reach ABM logic, one needs to implement that structure in the software to represent correctly the model. The model was built on *AnyLogic® 8.0.2* (https://www.anylogic.com/), the software is broadly used to simulate airport environments (e.g. Ma (2013), Lin (2014), Kalakou (2016)). Since *Anylogic®* software is based on a discrete-event structure that allows the introduction of agent-based modelling several structure schemes are possible. The flowchart representing passenger's activity choice needs to include *go to activity* to represent the interaction principle of the ABM (Figure 3.9): when moving towards the point of the next activity, the pedestrian may interact and, if **activated**, interrupt the first activity and proceed to the new one.

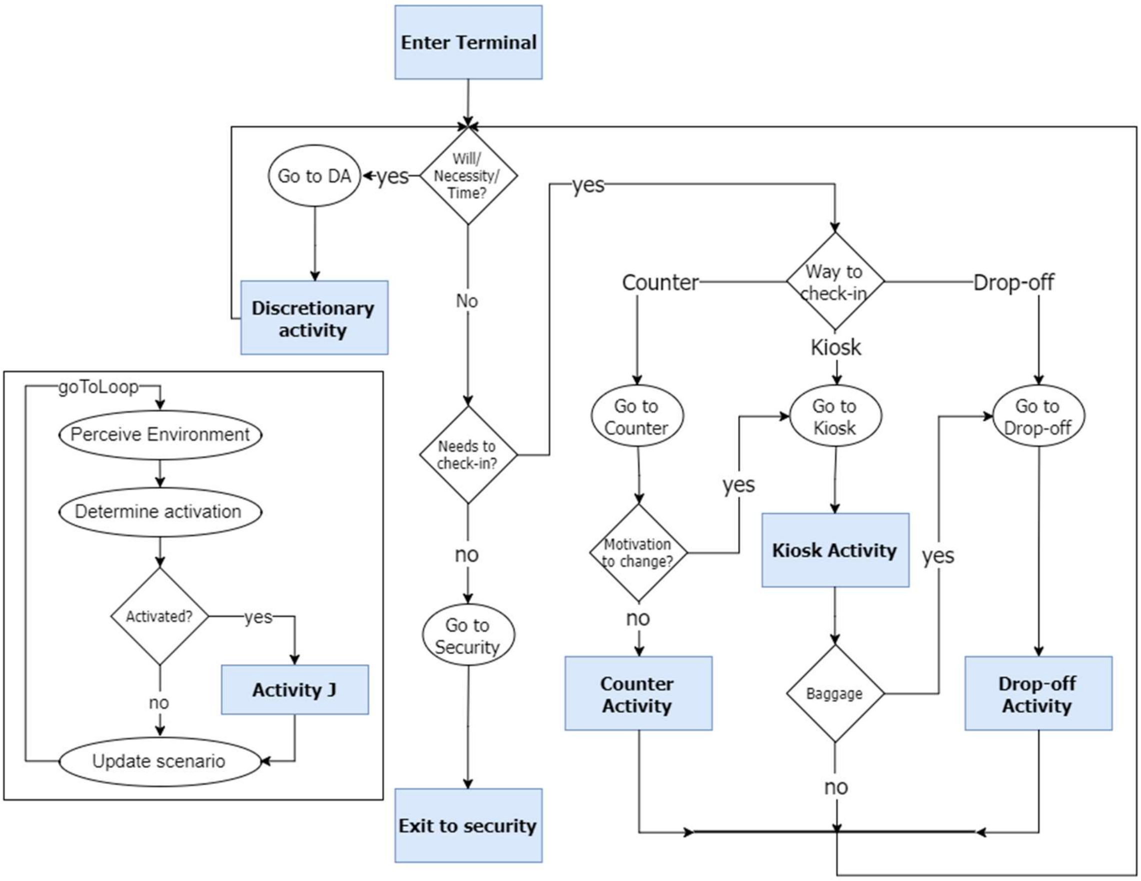
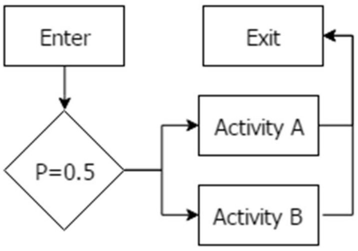
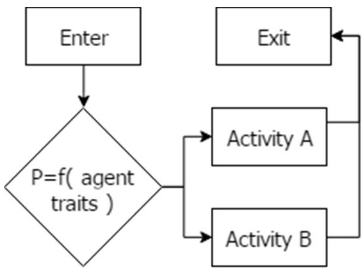
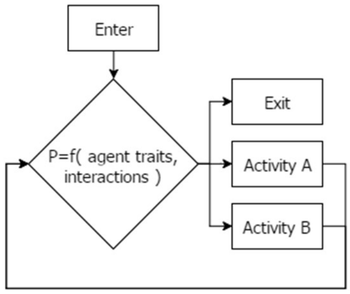


Figure 3.9 - Passenger activity and decision making.

First, the software scheme needs to be developed. Some possible schemes are pure discrete-event simulation, which means the system operates as discrete sequence of events, others are agent-based on a discrete structure meaning the probabilities are based on the agent (Table 3.8). Yet, these schemes fail to represent interactions and the possibility to change after activity choice.

To best achieve the goal of simulating interactions between agents a cyclic structure was created. This cyclic structure needs to assure two things: (1) the agent won't fall in a cyclic sequence, i.e. needs to have some exit point; and (2) there must be the possibility to interrupt the activity the agent is performing.

Table 3.8 – Different schemes of models' representation on discrete structures.

Discrete-event (Félix 2015)	Agent-based (Ma 2013)	Agent-based (proposed)
		
Continuous process	**Continuous process**	**Cyclic process**
No agent traits, probabilities based on the system itself.	Agent traits can be included and will influence the decision, probabilities based on agent traits.	Agent traits and interactions influence the decision; probabilities based on agent traits and environment characteristics, decision maker can alter his decision thus restarting the loop.

The developed model structure means there is no continuous activities, and the *go to* activities will send the pedestrian to where he wants to. The decision tree is in the agent itself and not on the environment. There is a source, a decision point (task verifier), activities, and an exit point creating the main model structure.

After defining the structure that will best suit our model (Figure 3.10), there is the necessity to define what agents/entities[4] will be introduced in the model: (1) Passengers; (2) Flights; (3) Service providers; (4) Check-in Counters; (5) Kiosk facilities; (6) Info signs; and (7) Lounge areas.

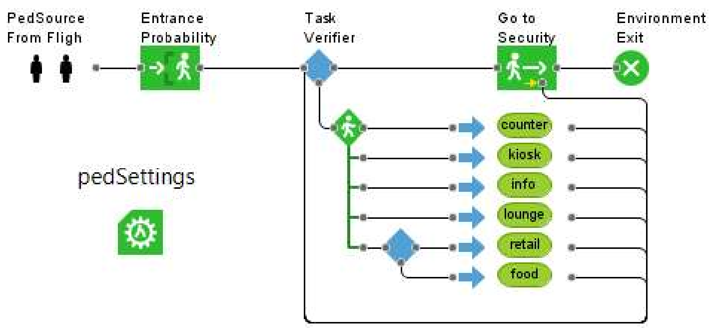


Figure 3.10 - Model structure in Anylogic 8.0.2

[4] Entities are elements that can be placed within the environment that serve as support for the agent (e.g. walls, doors, stores, flight entity etc.)

The organization of the proposed agent-based model simulation (ABMS) can be summarized into (Figure 3.11): (1) Inputs; (2) Inject passengers; (3) Passengers; (4) Activities; and (5) outputs.

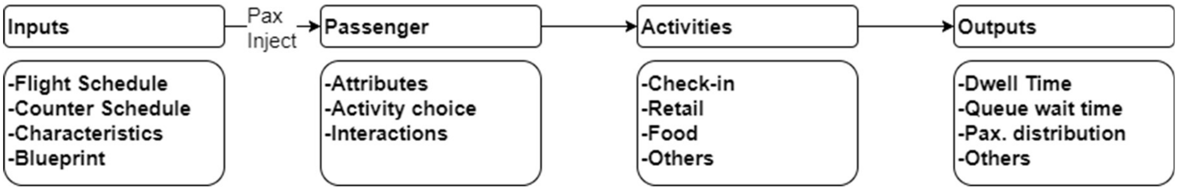


Figure 3.11 – ABMS simplification.

a) Inputs

The input parameters are: (1) model run time is 24 hours, from 00:00:00 to 23:59:59; (2) flight schedule; (3) counter schedule; (4) airport's passengers' characteristics; (5) all the ABM assumptions; and (6) airport blueprint.

All these inputs are variable for each airport, one can find the inputs for Lisbon airport in APPENDIX PARAMETERS FOR SIMULATION and APPENDIX BLUEPRINTS.

b) Inject passengers

Passengers are injected according to flight schedule and airport's passengers' characteristics. Flights represent an entity that attracts passengers to the model, therefore, according to flight departure hour and from the arrival pattern, each flight will inject passengers into the model (Figure 3.12).

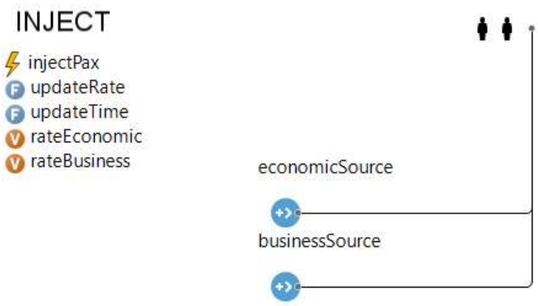


Figure 3.12 - Injecting passengers.

Two functions will be needed, one to determine if there is the need to update the injection rate for that flight, and another to determine which value should the injection rate be. These two functions can be found in APPENDIX SIMULATION FUNCTIONS.

c) Passenger

A required step is to certify every model unit performs correctly as agent-based model structure relies on individual agent's behavior and the interactions the agent performs (Lin 2014). Passenger agent will be a combination of parameters, variables and functions. Resulting in simple rules within the passenger agent that will create the complex environment of the model.

The passenger is divided in three processes (Figure 3.13): (1) attributes generation; (2) activity choice; and (3) interactions.

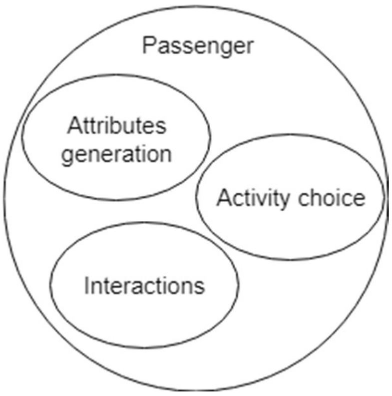


Figure 3.13 - Passenger structure

Agent variables (Table 3.9) are assigned to the agent according to airports characteristics and follows this technique: (1) get a random number for a determined parameter; and (2) use that number to get the airport's passengers' characteristics. After, a function will generate all the advanced characteristics of the passenger. This function can be found in APPENDIX SIMULATION FUNCTIONS.

Table 3.9 - Passenger variables

Variables	Type	Example
Age	Interval	[20;35]
TravelFrequency	Interval	[>3]
Native	Boolean	True
BusTravPurp	Boolean	True
BoardingPass	Boolean	True
DispatchBag	Boolean	False
EagernessToShop	Integer	2
LevelOfHunger	Integer	5
ComfortWhTechnology	Integer	1

The agent is now fully characterized and can determine his first task when entering the terminal. The function GoalGenerator() (found in APPENDIX SIMULATION FUNCTIONS) adds the next task to the agent itself according to all the agent variables. This is the generation of non-impulsive activities mentioned earlier. That function adds a Task to the passenger's taskList. From that list, the agent decides if he has another task to perform, or otherwise his taskList is empty and, therefore will exit the environment.

Other operational choices that occur with interactions in the environment such as walking speed variability, obstacle avoidance and leader-follower are embed in the software in a feature named pedestrian library. Pedestrian library enables an accurate representation of pedestrian interaction with obstacles and with other pedestrians after defining where the agent goes.

To represent the impulsive activities, the agent is continuously verifying agents at his range. If there is contact with another agent he will set the rules of engagement by the logic explained before: (1) in range; and (2) activated. If the agent gets activated by the other agent the previous task is put to second place or canceled and a new one is assigned, meaning the pedestrian will have a new destination.

Define field of view of the agent (Figure 3.14). Using β = 60º and range = 15 meters (Emrich et al. 2007). After determine Dijkstra et al. (2009) non-impulsive behavior framework (Figure 3.15). Determine if there are other agents inside the field of view and for those, if there is attraction: some conditions are met (Figure 3.16). Example, if the agents are autonomous drop-off counters the conditions are activation for comfort with technology and queue length. If the agents get activated he will jump to activated state and his current situation is canceled and a new task is added (Figure 3.17).

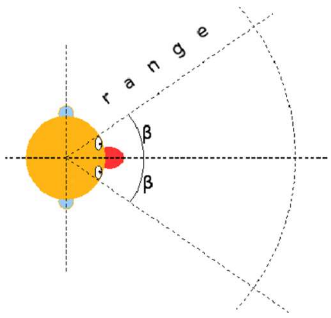


Figure 3.14 – field of view of pedestrian (Emrich et al. 2007).

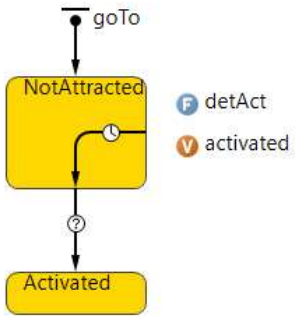


Figure 3.15 – Non-impulsive structure.

```
agent=null; //no agent inside field of view
    for ( agent g  : agentsInRange ( main.agents, fieldOfView , METER) ) {
//evaluate all agents inside field of view
      if(agents.contains(g)){ } //assure not repetitive evaluation
      else { // decision conditions code comes here
                   if ( //decision returns true ) {
                                     agent=g;
                                     activated=true;
                                     agents.add(g);
                   } else { //decision returns false
                                     activated = false;
                          };
                   };
            };
      };
    return agent;
```

Figure 3.16 – Function determine activation

```
if(currentBlock() instanceof PedGoTo)
      ((PedGoTo)currentBlock()).cancel(this); //cancel go to activity
if(currentBlock() instanceof PedService)
      ((PedService)currentBlock()).cancel(this); //cancel activity
tasks.addFirst(new Task(TaskType.Type, agent.getIndex(),0));
```

Figure 3.17 – Function when activated

d) Activities

Check-in counters and kiosks provide the place in which passengers perform aeronautical activities on the landside. Therefore, check-in counters and kiosks are fixed agents waiting for a passenger to interact with them. Info signs, service providers and lounge areas are used while the passenger stays in the terminal. The parameters in use are only applied to the correct agent. Thus, resulting in a set of parameters shown in Table 3.10.

Table 3.10 - Check-in Counters and kiosks parameters.

Parameters	**Type**	**Example**
CommonUse	Boolean	true
Company	Array	“Tap”
ID	Integer	2
Type	ServiceType	Sign
Product	ProductType	Food

To make interactions possible some parameters are not static thus creating the need for variables in each agent. Each variable is used with the right agent and they are represented in Table 3.11.

Table 3.11 - Dynamic variables.

Variables	**Type**	**Example**
QueueSize	Integer	7
Occupancy	Double	75%

All activities follow the same structure (Figure 3.18): (1) pedGoTo; (2) pedwait, performing the activity; and (3) pedWait2, updating the agent task. Also two routes are possible due to the possibility of cancelation due to interaction.

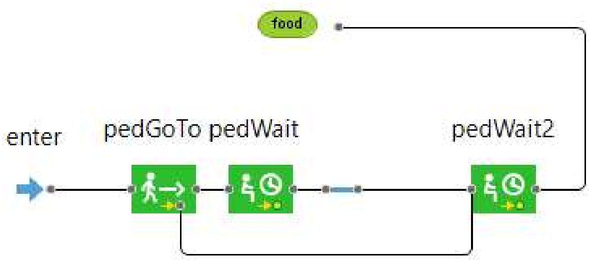


Figure 3.18 - Activities structure.

e) Outputs

Data collected from each run: (1) Dwell time; (2) Time to departure after finishing check-in (Check-in end time); (3) Queue waiting time economic; (4) Queue waiting time business; (5) Time left to board; and (6) Passengers inside terminal (in 20 minutes interval).

Output data evaluation

The first thing that should be done when evaluating a model is to determine if the results are an acceptable representation of the real system. Therefore, outputs obtained from the simulation runs must be compared to what is considered and observed *in situ* and some deviation (from target) analysis is done for those outputs. Since there is randomness while using distributions in model inputs, the next step is to perform several replications (n) to deal with the stochastic variations that result in measurements uncertainty from model runs and to increase outputs statistical significance.

The main focus is the time the pedestrian has to wait inside the terminal for each scenario. For each case, the daily passenger waiting time mean is observed from each run, an estimated value, μ, and an estimate of the standard deviation, σ, is obtained. Confidence intervals from parametric descriptive statistics analysis are reported. For that reason, one should first explore the normality of the output dataset before proceeding to use parametric analysis.

To test the assumption of normality, several methods could be applied. Two broad categories are found: graphical and statistical. Shapiro-Wilk's test has the best power for a given significance. This conclusion was found in 2011 when compared to Anderson-Darling's, Kilmogorov-Smirnov's and Lilliorfers's tests (Razali & Wah 2011). For that reason, Shapiro-Wilk's test is performed using an algorithm by Royston (Royston 1982). Assuming that the sample has n elements, the algorithm follows these steps:

1 – Sort the data in ascending order:

$$x_1 < x < x_n \qquad 3.3$$

2 – Obtain the m_n values:

$$m_i = NORMSINV^5 \left(\frac{i - .375}{n + 0.25}\right) \qquad 3.4$$

3 – Assuming $M = [m_i]$, then:

$$m = M.M = M^t M = \sum_{i=1}^{n} m_i \qquad 3.5$$

4 – Define coefficients a_i as follows:

$$a_n = -2{,}706056u^5 + 4{,}434685u^4 - 2{,}071190u^3 - 0{,}147981u^2 + 0{,}221157u + m_n m^{-0.5} \qquad 3.6$$

$$a_{n-1} = -3{,}582633u^5 + 5{,}682633u^4 - 1{,}752461u^3 - 0{,}293762u^2 + 0{,}042981u + m_n m^{-0.5} \qquad 3.7$$

$$a_1 = -a_n \; and \; a_2 = -a_{n-1} \qquad 3.8$$

$$a_i = \frac{m_i}{\sqrt{\epsilon}};\ 2 < i < n - 1 \qquad 3.9$$

[5] NORMSINV(x) = Inverse of the standard normal cumulative distribution with probability of

Where:

$$u = \frac{1}{\sqrt{n}} \; and \; \epsilon = \frac{m - 2 * m_n^2 - 2 * m_{n-1}^2}{1 - 2 * a_n^2 - 2 * a_{n-1}^2}$$

5 – Obtain the W statistic:

$$W = \frac{(\sum_{i=1}^{n} a_i * x_i)^2}{\sum_{i=1}^{n}((x_i - \bar{x})^2)} \qquad 3.10$$

W is the square of the correlation coefficient between a_1< a_i< a_n and $x_1 < x_i < x_n$. It is also true to assume for values of n between 12 and 5000 the statistic $\ln(1 - W)$ is approximately normally distributed.

6 – Test the statistic using standard normal distribution:

$$z = \frac{\ln(1 - W) - \mu}{\sigma} \qquad 3.11$$

The test should not be significant to meet the assumption of normality, i.e. the p-value must be greater than the significance level α, which corresponds to the probability of rejecting the null hypothesis. When the null hypothesis is true two assumptions can be used:

- H_0 – The data is not significantly different than a normal population; or
- H_1 – The data is significantly different than a normal population.

Since the test is biased by sample size, meaning the test may be statistically significant from a normal distribution in any large sample, a Q-Q plot is used additionally for verification. Q-Q plot is generated for each sample size to graphically visualize the sample distributions comparing them to the standard normal distribution – Normal probability plots N (0,1).

As each run is independent and the sampling is random, if the errors in the passenger waiting times have a normal probability distribution, then the probability y distribution for the error in the sample normal mean, normalized by the standard error in the sample average, is the t-distribution. It is possible to conclude that there is 1-α probability that the confidence interval (CI) contains the true value of μ. The value used for α is 0.05 (95% confidence)

$$CI = \mu \pm w = \mu \pm t_{n-1} * \sigma \qquad 3.12$$

Where:
$w = confidence\ interval$
$t_{n-1} = t - statistic\ corresponding\ to\ the\ \frac{\alpha}{2} probability$
$\sigma = standar\ error\ of\ the\ mean$

To ensure mean statistical significant of the data obtained from each run, the number of replications of the model is increased by 10 until assumption of normality for the sample data is acceptable and the value W is below 1. Then the data is evaluated according to that number of replications and then parametric evaluation is performed.

3.6 Model validation

Model validation is the last step on a model development, requiring large amount of detailed data to validate pedestrian behavioral models, is one of the most difficult steps in crowd modelling and simulation. It is hard to introduce real world data outputs in a pedestrian model since systems are deeply complex and human activity choice is unpredictable. This leads to the conclusion that validation of pedestrian models still is a major issue for modelers (Hu et al. 2012). Many validation approaches are possible, video films, photographs, direct observation and inquiries are the most common data retrieving form to ensure a correct validation of the models when studying crowds. Face validity, empirical validity and comparison to other models are commonly used criteria when assessing agent-based models (Koh & Zhou 2011; Sargent 2004).

Face validity ensures a conceptual model validity through expert's observation. Face validation. This technique is asking knowledgeable people about the system and the model relationships, it determines if the logic in the model is correct and if the model input/output relationships are reasonable (Sargent 2004).

When the model structure was first presented to Eng. Sophia Kalakou during a meeting at ***vtm - Consultores de engenharia e planeamento*** headquarters, some adaptations were proposed. After, in May 5th, 2017 the finished model structure was evaluated and approved by the same expert. 2D animation of the simulation tool plays a vital role in face validation. Software tools enable to observe passenger behavior, such as walking, waiting and activity choice in the animation. The interaction between passengers and the airport's environment can also be analyzed. Empirical validation is the knowledge received from comparing the model outputs and those received from the real system. Empirical validation is one effective approach to establish model validity (Koh & Zhou 2011). Comparison to other models consists in comparing both the logic and the parameters from previously validated models.

Other validation methods were used and are presented below:

- The number of runs is enough to ensure the sample data is normally distributed;
- All the model code was debugged and every function and assumption was tested independently to ensure correct coding;
- All model principles were based on previously validated models;
- Review of the assumptions by supervisors;

After proper number of runs for the simulation model the data obtained is compared to findings of airports. This step ensures a correct statistical validation. Data collection from a real airport is extremely labor demanding while being time consuming (Livingstone et al. 2012). Available data for airports in general is limited.

3.7 Chapter review

This chapter want meant to explain the development of a pedestrian model of an international landside terminal. The model has explicitly introduced interactions with several elements of the environment which allowed the model to be more realistic and be closer to a real-world airport terminal.

The three key model elements of an agent-based model were explored accordingly: (1) a set of agents – with own basic traits and advanced characteristics; (2) model environment; and (3) agents' interactions with environment. The passengers are assigned with basic traits (i.e. age, gender, travel frequency, etc.) that will translate into advanced characteristics (i.e. comfort with technology, eagerness to shop and others).

Agents arrive in the simulation environment according to information retrieved from a flight schedule. Flight departure time and passenger number on board are uploaded into the airport arrival pattern to inject passengers. Pedestrian movement and activity choice is governed by predefined rules influenced by advanced characteristics. The actions depend on what the passenger needs and how much time he has left to plane. After defining his set of activities, the pedestrian may interact with other objects such as stores, cafes or other check-in solutions that will affect the initial activity set choice.

Although principles used in the model are sufficient to validate the model, some rules need to be improved and calibrated. Statistical validation is performed after application to the case study.

Chapter 4 - Case study: Lisbon's airport terminal 1

The following chapter is meant to present Lisbon Humberto Delgado's international airport to which the model will be applied. All data collected regarding the airport will serve as input to the simulation model. The structure of this chapter is composed by an introductory part where the airport is presented with all characteristics and facilities that represent the environment in the simulation model. Passenger's characteristics is then reviewed. Scenario introduction is followed by simulation runs and results presentation. Results' discussion will conclude this chapter.

4.1 Airport presentation

Lisbon Humberto Delgado's international airport is Portugal's biggest airport and will be used as the case study. The airport was established on October 15th, 1942 and is composed by two passenger buildings and two runways. In 2016 total number of served passengers was around 44 million (ANA 2018). Figure 4.1 is a schematic used in the simulation environment of the departure floor of the passengers building which falls into the scope of this dissertation, complete blueprint of the building can be found in APPENDIX BLUEPRINTS.

. This is the area inside the terminal where the studied was conducted. Check-in and security screening take place in this area and many discretionary activities are found distributed over the building. Before security control there are several areas: (1) check-in areas; (2) retail areas; (3) coffee shops areas; and (4) leisure areas i.e. a lounge area.

Facilities

Terminal 1 is the main building of the airport. To provide all needs of the players inside the airport it has several types of areas inside. Five main entrances serve the check-in areas and different discretionary activities can be found.

The terminal building has five main entrances:

- Departures entrance: focused in passenger drop-off point for private and public transportation (taxis, buses and shuttles),
- Metro entrance: used for passengers arriving by metro,
- Park 1 entrance, frequently used by people accompanied who park their car,
- Park 2 entrance, this is the arrival park which may be an alternative to park 1 and,
- Arrival connection entrance, there is a connection to the arrival hall that can be used as an entrance.

The building has three floors and lack of open space areas is observed. This configuration is assumed to lead to a pedestrians' low perception of the environment due to multiple obstacles in their field of view (Kalakou 2016). First-time passengers may find the terminal confusing and have to rely purely on the signage system.

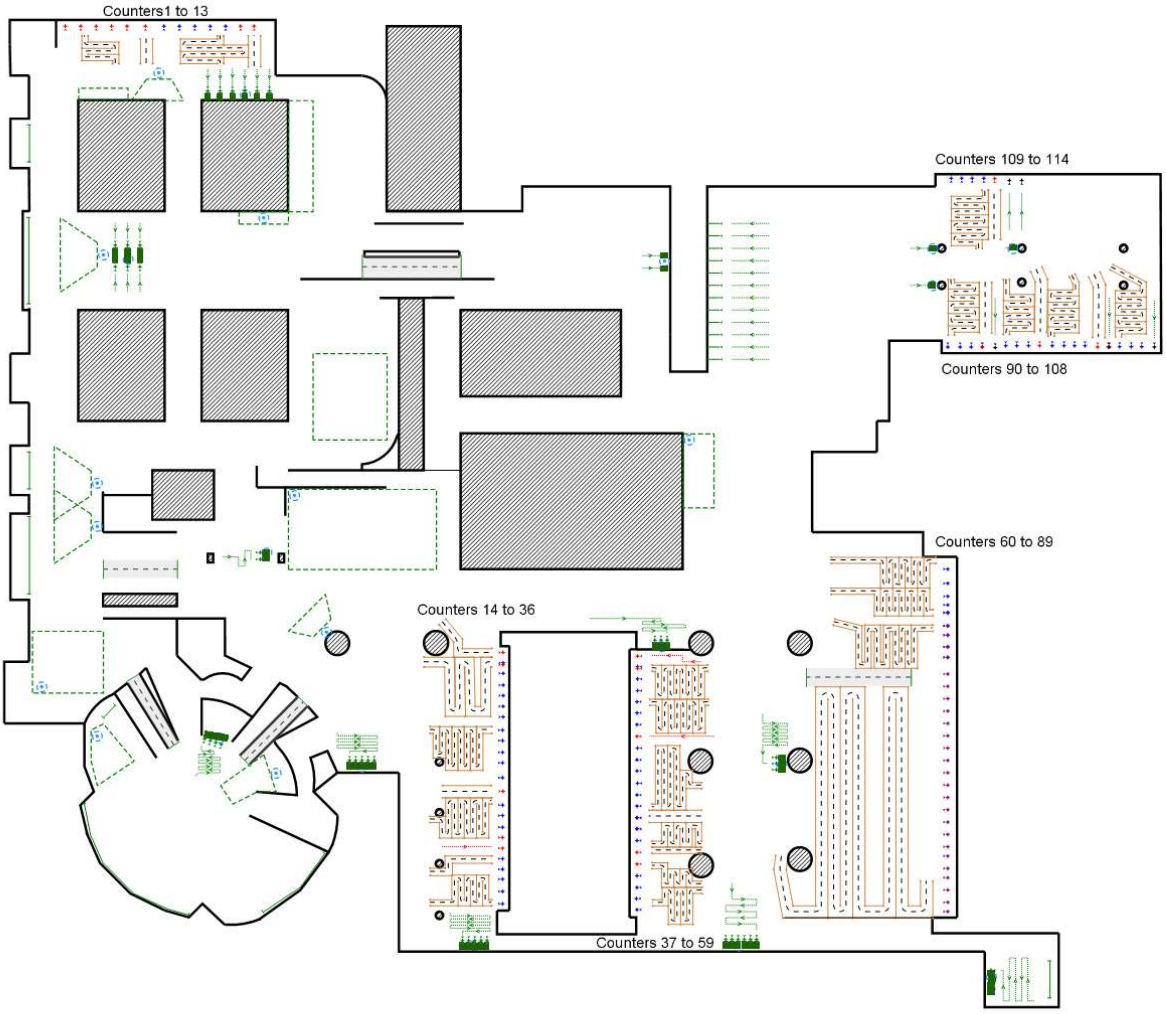


Figure 4.1 - Departure Hall.

Each entrance has the corresponding probability of been chosen by the passenger:

Table 4.1 - Entrance probability. Félix (2015).

Entrance	**Probability**
Main	45%
Metro	15%
Park1	35%
Arrivals	3%
Park2	2%

The check-in areas serve the airlines flying from Lisbon terminal 1. Currently the terminal is equipped with distinct types of check-in solution:

- Counters:
  - Dedicated;
  - Flexible assignment;
  - Dedicated-use assisted bag drop-off; and
- Kiosks.

A counter schedule is needed to complete the information regarding check-in. The schedule determines whether a certain counter is operational or not at certain time and determines the counter operating airline. This scheduled was obtained by author's observation of check-in operations inside the terminal. Table 4.2 presents an excerpt from the complete file that can be found in APPENDIX PARAMETERS FOR SIMULATION. The type of queues used are the same as in reality: a snake queue line with the rule first-come, first-serve (Figure 4.2).

Table 4.2 – Excerpt from counter schedule.

Hour	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
05:00															
05:30															
06:00															
06:30			AZ												
07:00															
07:30															
08:00			AZ												
08:30															
09:00															
09:30															
10:00															
10:30												TAAG			

	Eco. counter
	Bus. counter
	Flight info

Figure 4.2 - Queue policy - 2D simulation experiment

Kiosks are spread over the terminal, serve to print the boarding pass for the following airlines:

Air-Canada	British Airways	KLM	TAP*
Air France	Brussels airlines	Lufthansa	Turkish Airlines
American Airlines*	Delta	Royal Air Maroc	United Airlines*
Azores Airlines	Iberia	TAAG	

*Kiosks can also print baggage-tag for these companies.

Waiting areas are spread over the terminal, passengers prefer to wait at a sitting bench. There are cafes and benches near check-in area and, also a lounge area is found inside the terminal with 60 seats available.

Retail shops are concentrated in the middle area of the terminal, the offer is quite limited having one fashion, one make-up and one newsstand. Other service stores can be found such as a bank, a post office a travel agency and a phone store. As for food and cafes the offer is spread around the terminal, many places can be found serving diverse types of food.

Current expected developments

By observation the main issue on check-in operations is related to the non-existence of specific queue for assisted bag drop-off counters. In terms of processing passengers on the landside, the expected developments are related to automated self-service bag-drops. Installing this new equipment seems at first, beneficial due to the shorter processing times they enable the possibility to split queue lines between the kiosks and the drop-off counter.

Figure 4.3 - Bag drop at Paris Charles de Gaulle Airport.

Most of the bag-drop systems are retrofitted into existing counters, resulting in a minimum alteration of the terminal's area offering maximum flexibility. Also, kiosks for this solution offer flexibility to integrate classical check-in counters according to Phillipe Laborie in Symonds (2017). Also, step-by-step integration is possible avoiding completely shock for passengers. Optimizing is needed and common-use passenger processing systems (CUPPS) help facilitate the fast-changing operations of the airlines.

Flight schedule

Being the main reason of attraction to the airport, a flight schedule must be presented in order to have pedestrians injected in the model. A full day of mid-season is chosen, in this case May 11th, 2017. The airport comprises a total of 30 airline companies during that day, with a running mean of 80% of full capacity. Each flight has a specific airplane model, this information was crossed to obtain the total number of passengers during that day. Resulting in a total of 216 flights departed from the airport, with a total of 27207 passengers.

An excerpt from the information retrieved from ANA (2017) and crossed with airplane information from SeatGuru (2017) is shown in Table 4.3. Complete information regarding full day is found in APPENDIX PARAMETERS FOR SIMULATION.

Table 4.3 - Excerpt from flight schedule

STD	Flight Code	Destination.	Airline	Airplane	EcoSeats	BusSeats
6:00	LG3752 A	LUX	Luxair	B737 (LX-LGS)	186	0
6:05	LH1793	MUC	Lufthansa	A321 (D-AIDA)	160	30
6:30	S4121	PDL	Azores Airlines	A310 (CS-TKN)	204	18
(…)	(…)	(…)	(…)	(…)	(…)	(…)

4.2 Passengers

Passengers using Lisbon's airport terminal 1, have distinctive characteristics that can lead to complete different arrival patterns, ways to perform activities and check-in preferences. The data presented in next section was gathered by Kalakou (2016). The information was captured during the first week of March 2014, from 10 am to 9 pm. 529 passengers completed valid responses. If some information was obtained from other author reference appears.

Lisbon's landside airport terminal is well served of fixed signaling and people don't have trouble finding their way through the terminal, avoiding adaptations to the route chosen by confuse signaling.

4.2.1 Passengers characteristics

As for the basic traits of the passengers, it was found 43% of the passengers were Portuguese, 57% of those lived in Lisbon. 65% were male and only a small percentage felt stressed to perform all the activities inside the terminal (10%). Almost 60% of the passengers were familiar with the airport facilities. Figure 4.4 presents information regarding age distribution and travel frequency.

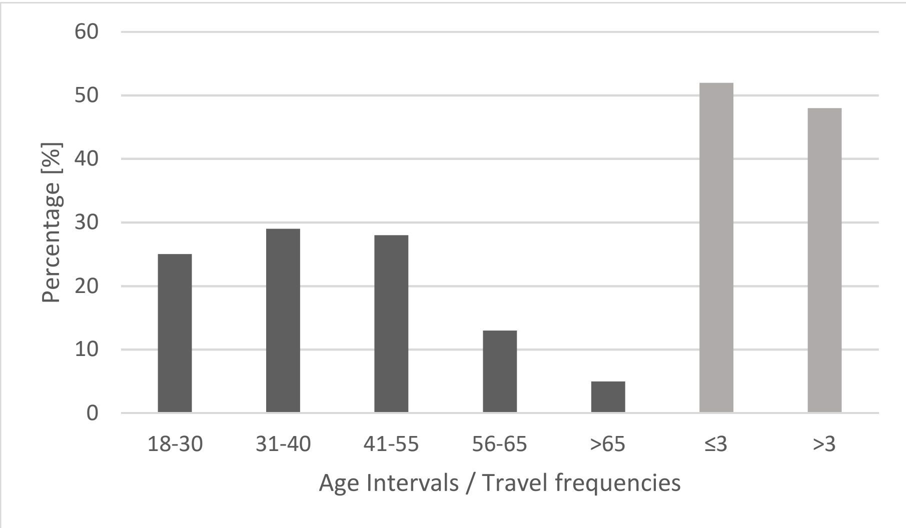


Figure 4.4 - Age and travel frequency distribution.

4.2.2 Passengers arrival pattern

Passengers' arrival pattern should not be done at regular pace, and findings show how it can affect the check-in assignment (Park & Ahn 2003). Arrival-time pattern in 2016, in Lisbon airport terminal is presented in Figure 4.5. The findings by the author are simplified with the same methodology Félix (2015) presented: Three intervals of 60 minutes were created: (1) 220 to 160; (2) 160 to 100; and (3) 100 to 40. Note that, these principles go according to Ashford et al. (2011):

- Most of the passengers arrived 60 minutes to flight departure;
- There is a peak around 120 to 100 minutes to flight departure; and

- Non-Schengen flights' passengers tend to arrive sooner.

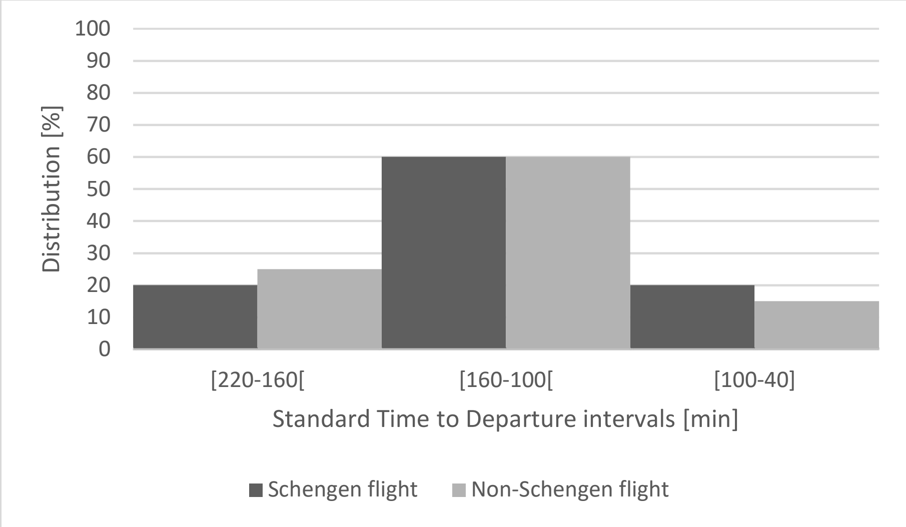


Figure 4.5 - Passengers' arrival distribution.

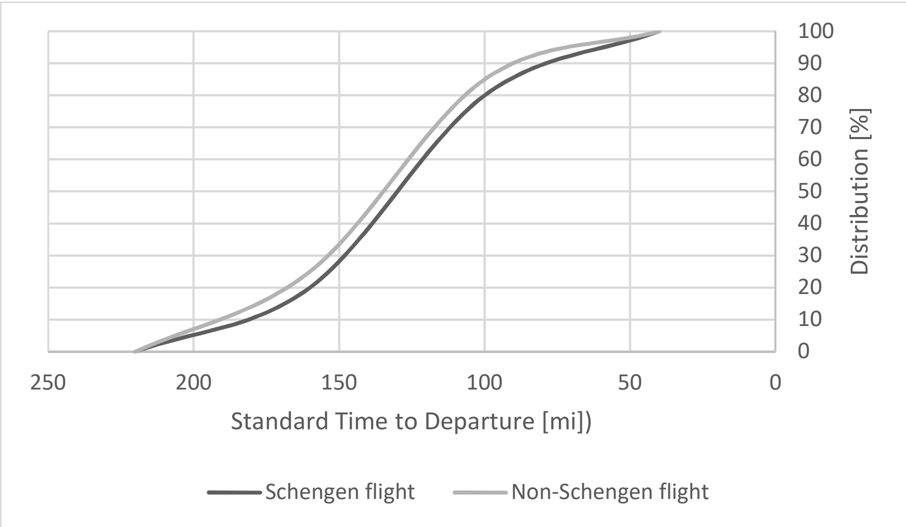


Figure 4.6 - Cumulative passengers' arrival distribution.

4.3 Scenarios

As it is being remarked throughout this dissertation, the developments inside the terminal by the introduction of modern equipment will only improve the system itself if perceived and adopted by the passengers. The introduction of full self-service technologies by its own won't improve the system unless it fits the needs and the requests of the users. The check-in area has been subject of self-service solutions introduction. Other airport terminals already adopted and will sooner or later be implemented in Lisbon's airport terminal 1. Therefore, four scenarios (1 base scenario + 3 test scenarios) reflecting different acceptance levels to this recent technology were chosen to assess operational gains to the terminal.

Assumptions

Evidence suggest through other airports' analysis not all airlines are yet inclined to offer a fully self-service check-in for their passengers, and some do not agree with the use of common-use counters. This results in higher level of uncertainty when deciding which airlines are prone to adopt this technology. Therefore, only some airline companies will provide the automated service. The assumed airlines that will offer the service are presented in Table 4.4. This list results from observation of other airports or the adoption of self-service kiosks on Lisbon Airport.

Table 4.4 - Airlines adopting self-service drop counters.

Air-Canada*	British Airways	KLM	Turkish Airlines
Air France	Brussels airlines	Lufthansa	United Airlines
American Airlines	Delta	Royal Air Maroc	
Azores Airlines	Iberia	TAP	

Each airline will dedicate one fully automated counter for their passengers, with its own queue, except for TAP that will use a total of 5 automated counters. Common-use automated counters are not yet an attractive solution as airlines don't adopt CUPSS despite all the effort done in that direction. The rules for these counters are similar to the classic counter except: (1) no need for an operator (2) faster processing times and (3) each airline will use one allocation slot for the autonomous device, that slot will have its own queue.

As for the passengers, the rules of activation for these new devices maintain will be subject of testing. Queues and comfort with technology affect the choice of proceed to this new method. If the passenger is activated by the kiosk device, he will follow to drop-off counter. Also, the possibility of a passenger arrives to the check-in counter, interacts with the self-service drop-off and proceed to it is possible. In this case, the passenger will quit the traditional counter and proceed directly to the drop-off counter. Only passengers from the airlines with this technology are attracted. All the remaining passengers proceed as they would in the base scenario.

Running scenarios

Four running scenarios were chosen to assess the variations of level of service provided by the airport. There will be a variation in the activation level for this modern technology for distinct levels of comfort with technology (Table 4.5). This approach aims to represent the adoption and likelihood of a passenger adopt some solution when presented with newer devices.

Table 4.5 - Activation for each scenario according to comfort with technology.

Comfort with technology	Base Scenario	Scenario 1	Scenario 2	Scenario 3
0	00%	00%	05%	10%
1	17%	17%	34%	50%
4	70%	70%	95%	100%

Base scenario aims to represent the actual terminal operations and serve as comparison to the other three test scenarios. These base scenario, will be subject of data validation with actual data retrieved from the airport. After validation, data is collected and will serve as base to assess fluctuations in the parameters when running the three test scenarios.

First scenario uses current activation probability for todays' kiosks, it is expected that this scenario will reduce queues in comparison to traditional counter, resulting in shorter dwell times for passengers and shorter waiting times in queues. Passengers using traditional counters will see their waiting times increased but in the daily operations, little to no different should be observed

The second scenario is the representation of higher adoption of the technology. All three levels of comfort with technology can be activated. This scenario is aimed to represent the best adoption rate for the scenario resulting in minimum waiting time for the passengers. Results from this scenario will greatly improve the base scenario and the first scenario.

Last scenario represents the majority of passengers being acquainted with self-service counters and wanting to use the technology. By such adoption level it is expected the automated counters surpass their optimum utilization level and start to increase waiting times. This is a scenario representing the needs to adopt the solution in more counter.

Results will be collected by the following sequence:

- Assure the simulation is having representative number of runs;
- Collect information from base scenario and validate data collected;
- Examination of variables by having representative number of runs for each scenario:
    - Waiting times;
    - Dwell times; and
    - Passengers distribution interval inside the terminal.

4.4 Results

4.4.1 Base scenario

After 30 replications, the p-value obtained from the WS test was 0,32 (greater than α = 0.05). Thus, the assumption of normality distribution is not rejected. It is also confirmed by the observation of the QQ-plot. Queue waiting times mean distribution of the 30 replications can be analyzed in Figure 4.7.

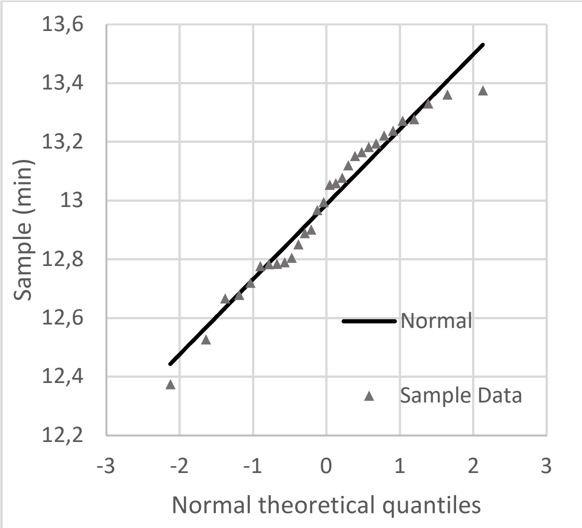


Figure 4.7 - Normal probability plot - 30 replications

Each replication runs for about 15 minutes. More extensive data for the queue waiting time is presented in Table 4.6. The CI for the sample queue waiting time mean is approximately [12:58 ± 00:24]. It is reasonable to assume the reference value for the base scenario queue waiting time mean is between 12:30min and 13:30min. Further analysis on data retrieved from the 30 replication is presented below.

Table 4.6 - Base scenario queue waiting times - 30 replications descriptive statistics

Parameters	**Economic Passenger [mm:sec]**	**Business Passenger [mm:sec]**
Mean	12:59	02:31
Median	10:03	01:05
Peak Hour Waiting Time	24:58	-
80^{th} percentile	16:22	-
95^{th} percentile	28:05	03:21

Ashford et al. (2011) advises the maximum queue waiting time for economic counters to be under 30 minutes and for business to be under 5 min. Values from the 30-replication simulation model are within these values. Félix (2015) points a value of 15:00 min for the 80^{th} percentile while our model has 80^{th} percentile of 16:22 min. Peak hour was obtained during 8:00 am and 9:00 am.

Two observations were made to the check-in area to measure and validate the data obtained September 5th, 2017 and September 6h 2017. Three points that were obtained through staff survey: (1) The check-in area is much more crowded than one year ago; (2) Tap flights were being delayed due to longer queue waiting times in Tap check-in counters; and (3) Queue waiting times during morning peak hour could arrive to 30 minutes.

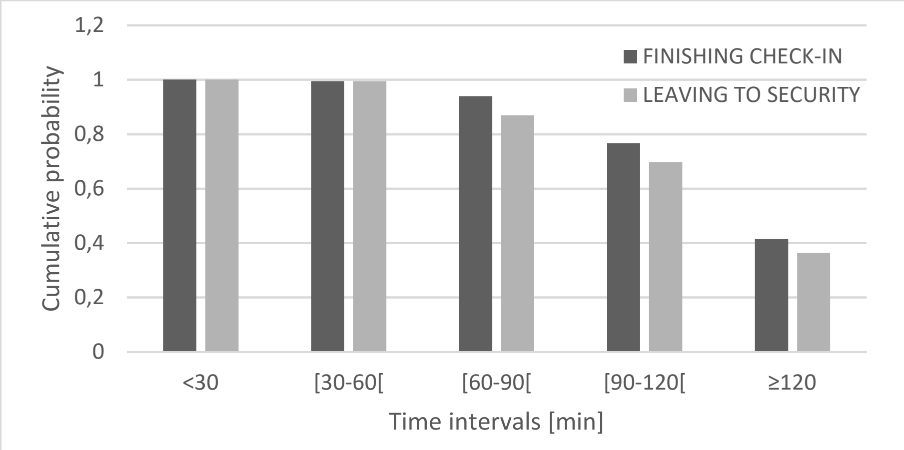


Figure 4.8 - Cumulative distribution for time left to board, when finishing check-in and when leaving to security.

95% of the passengers still leave to security with a minimum of 44:45 min left to board, and 76% of the passengers finish check-in with 90 minutes to flight departure scheduled time. Findings by Kalakou (2016) indicate a 70% passenger rate for the 90 minutes threshold and points a mean of 25 minutes of dwell time. Our model for the 30-replication sample retrieves a dwell time of 25:31 minutes.

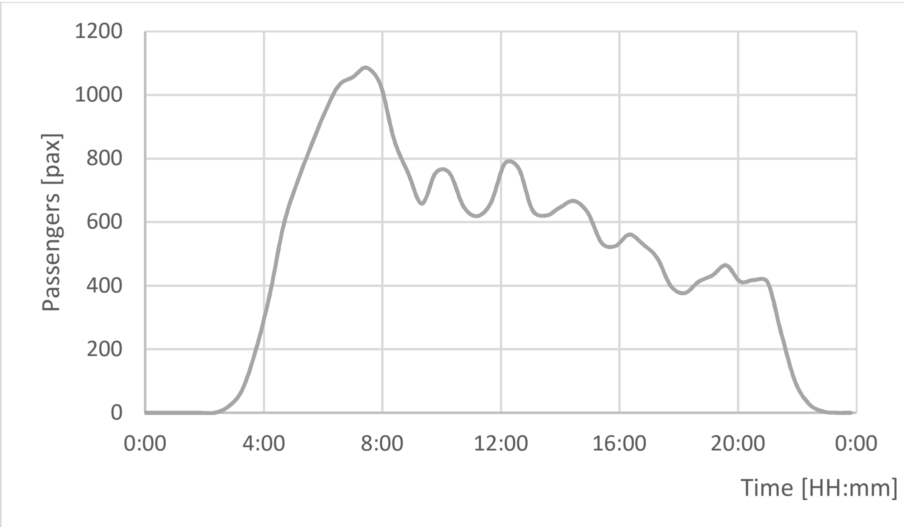


Figure 4.9 - Passenger distribution inside terminal

Pax distribution inside the terminal is found in Figure 4.9. Observing the data, the author concludes this is a typical distribution inside the terminal (de Neufville & Odoni 2013): (1) Morning peak hour busiest of the day; and (2) Lunch peak hour greater than afternoon peak hour. From data collected by direct observation and survey, adding to collected information from other authors in Lisbon terminal 1 airport, the author concludes the data obtained from the 30-replication fit the data from the real system thus statistically validating the model.

4.4.2 Scenario 1

For the first scenario, the number of replications to accept the normality of the sample mean was 30 replications. The p-value obtained with the WS test was 0,77 (>0.05). The Q-Q plot is presented in Figure 4.10.

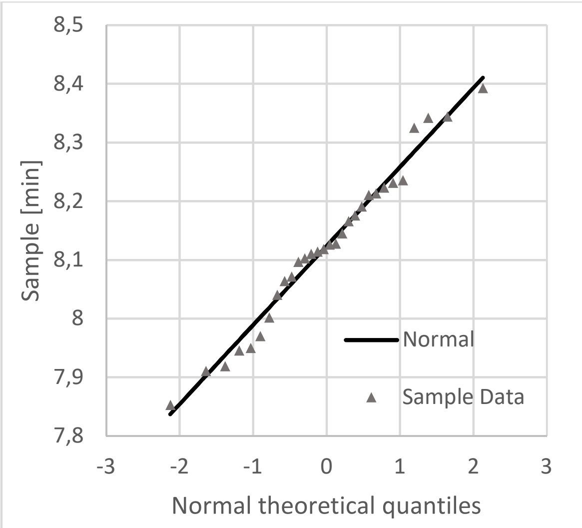


Figure 4.10 - Normal probability plot - 30 replications.

When introduced to the autonomous check-in this scenario considers the attraction rate to be the same as it is today for the kiosks. The descriptive analysis for the 30-replication output data of passenger queue waiting time is presented in Table 4.7. The Confidence Interval for the sample passenger queue waiting time mean is approximately [08:05 ± 00:15]. Meaning that 95% of these CI for the mean will contain the true sample mean, which is approximately less 4 minutes than base scenario.

Table 4.7 - Scenario 1 queue waiting times for 30-replication sample.

Parameters	Economic Passenger [mm:sec]	Business Passenger [mm:sec]
Mean	08:05	02:36
Median	06:24	00:59
Peak Hour Waiting Time	09:40	-
80th percentile	12:57	-
95th percentile	19:22	03:35

Despite what was expected, even a low adoption of the system brings several improvements to the passenger's queue waiting time. It is also noticed a huge improvement during peak hour period. In terms of business passengers, it is visible little to no difference. Business passengers preferer the offered dedicated service and therefore don't perceive great advantage to fully automated counters.

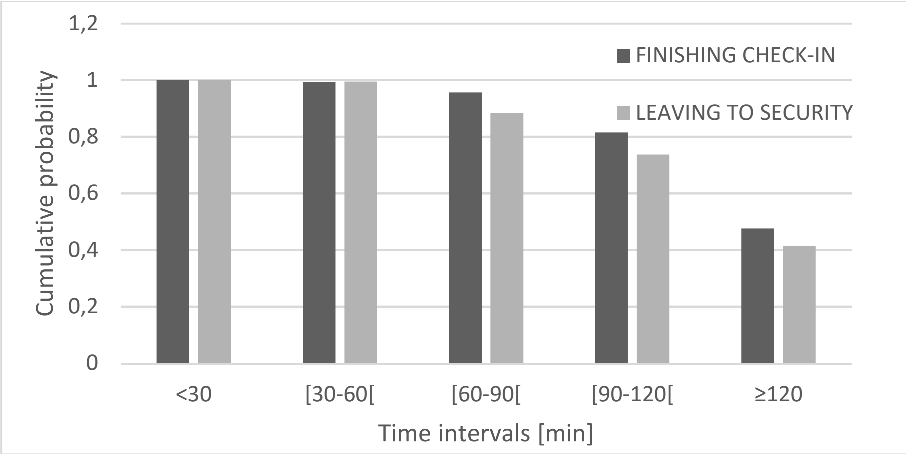


Figure 4.11 - Cumulative distribution for time left to board when: finishing check-in and leaving to security.

82% of the passenger finish check-in with more than 90 minutes left to board while 95% of the passengers leave security with more than 46:26 min left to board. The 30-replication sample indicates a dwell time of 22:04 minutes.

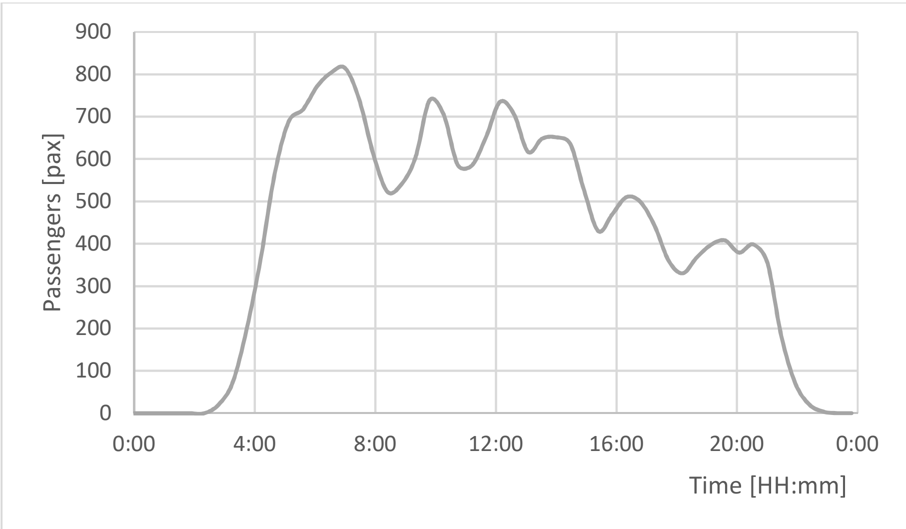


Figure 4.12 - Passenger daily distribution inside terminal.

When analyzing data obtained from the 30-replication run, it indicated automated machines are not working at its fully since the passengers' queue waiting time is more than 5 min. (the optimum waiting time according to the new LOS). The improvements at this point are for the ones who adopt the autonomous check-in as they beneficiate from the fewer passengers adopting it as well. Though, by observation of the simulation running: even a low activation rate for this new technology brings improvements for the traditional counter and for the overall operation of the terminal.

4.4.3 Scenario 2

After 40 replications, the sample mean obtained a p-value of 0,29 greater than α. The normality of the data output can also be observed in the QQ-plot presented in Figure 4.13.

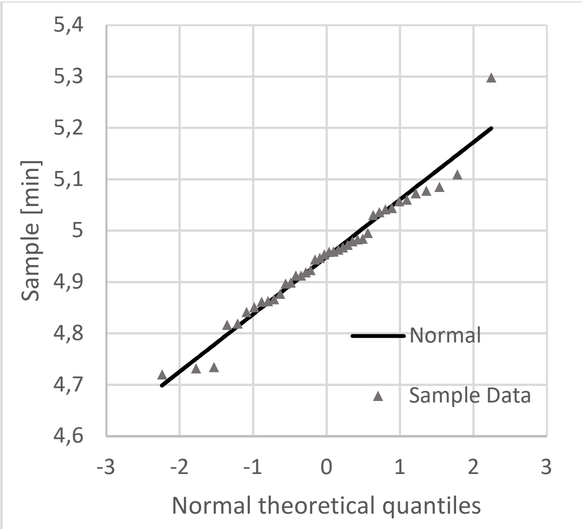


Figure 4.13 - Normal probability plot - 40 replications

This scenario simulates a greater activation for the autonomous check-in solution. According to SITA (2017) the preference for autonomous solutions is growing and passengers prefer self-service options. For this scenario the CI for the passenger's mean queue waiting time is [04:57 ± 00:10] which indicates the mean value of waiting times is around 5 minutes (the optimum time for autonomous solutions according to the new LOS). More descriptive data for the 40 replication sample is found on Table 4.8.

Table 4.8 - Scenario 2 queue waiting times - 40 replications

Parameters	Economic Passenger [mm:sec]	Business Passenger [mm:sec]
Mean	04:56	02:39
Median	03:00	01:01
Peak Hour Waiting Time	06:32	-
95th percentile	14:02	03:25

Being the scenario, which intends to represent a higher adoption of the system, two key points result in such an improvement from the base scenario: (1) a high quantity of passengers move to the new solution that has higher processing rates; and (2) the passengers who still prefer the counter now face less crowded queues. One improvement should be done at this time: cease traditional counters leading to increasing queues and waiting times resulting in more people wanting the autonomous solution (Castillo-Manzano & López-Valpuesta 2013).

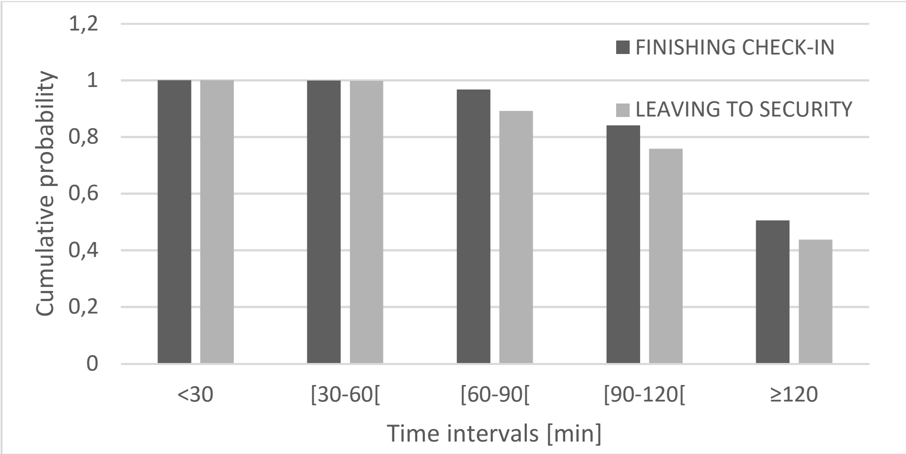


Figure 4.14 - Cumulative distribution for time left to board when: finishing check-in or leaving to security.

The mean dwell time of the passengers, for this scenario, reaches the minimum of 20 minutes. While 84% of the passengers now finish check-in with more than 90 minutes left to board, 95% of the passengers still have at least 48 minutes to pass security and board.

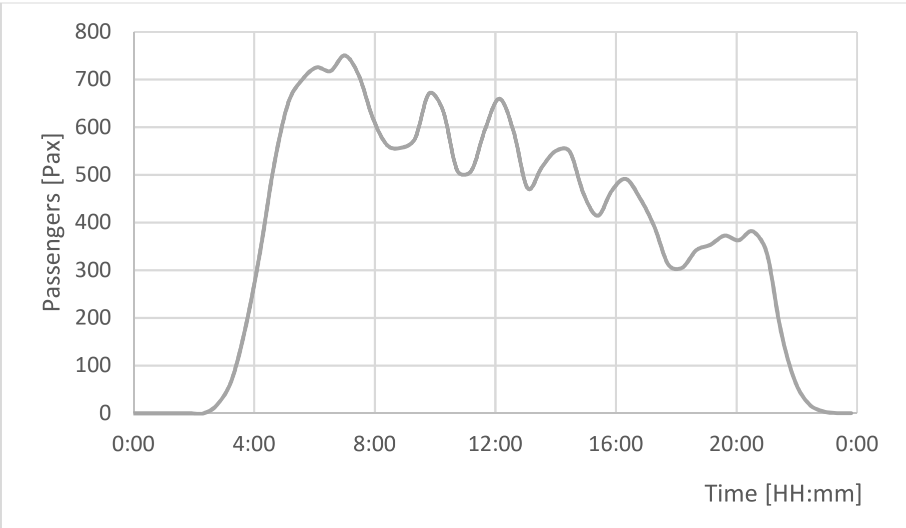


Figure 4.15 - Passenger daily distribution inside terminal.

Observing the daily distribution, it is possible to understand the use of autonomous solutions reduces the peak values and more rapidly processes passengers inside the terminal. This is the best adoption rate for the assumptions made previously. This activation level leads to the best operational functionality for this solution. If the activation/adoption for the autonomous technologies reached this level, there would be a reduction in the need for the check-in area by: (1) reducing traditional counters; and (2) need less number of autonomous counters as they have higher processing rate.

4.4.4 Scenario 3

For the last case, the number of runs not to reject the normality of the sample is 20. From the WS test, the pFrom the WS test, the p-value obtained was 0,68 (greater than α). The normality of the data output can also be observed in the QQ-plot presented in Figure 4.16.

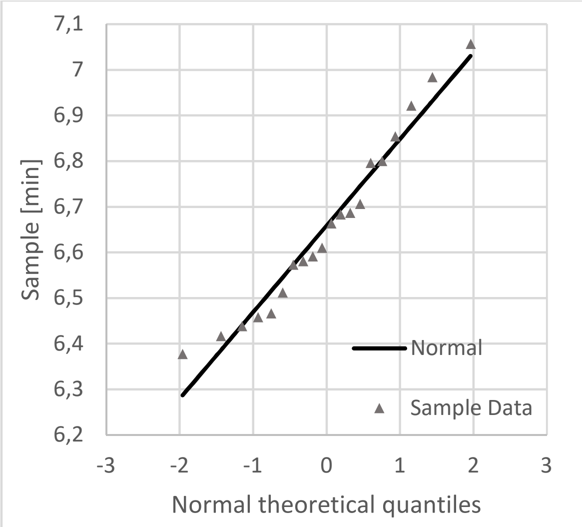


Figure 4.16 - Normal probability plot - 20 replications.

The third scenario presents the situation where the solution adopted is not enough, and automated equipment is becoming saturated and increasing waiting times. The confidence interval for the sample queue waiting time mean is approximately [06:40 ± 00:20]. More extensive data on the 20-replication sample is found in Table 4.9.

Table 4.9 - Scenario 3 queue waiting times - 20-replication.

Parameters	Economic Passenger [mm:sec]	Business Passenger [mm:sec]
Mean	06:38	02:28
Median	04:50	00:58
Peak Hour Waiting Time	13:42	-
95th percentile	18:08	03:21

From scenario to scenario the improvement has been seen, yet when this activation level is reached it starts decreasing, and waiting times start to increase. This is result of the saturation of the solution adopted. Meaning it needs a better rearrangement of the use of autonomous solution by increasing the number of self-service counters offered.

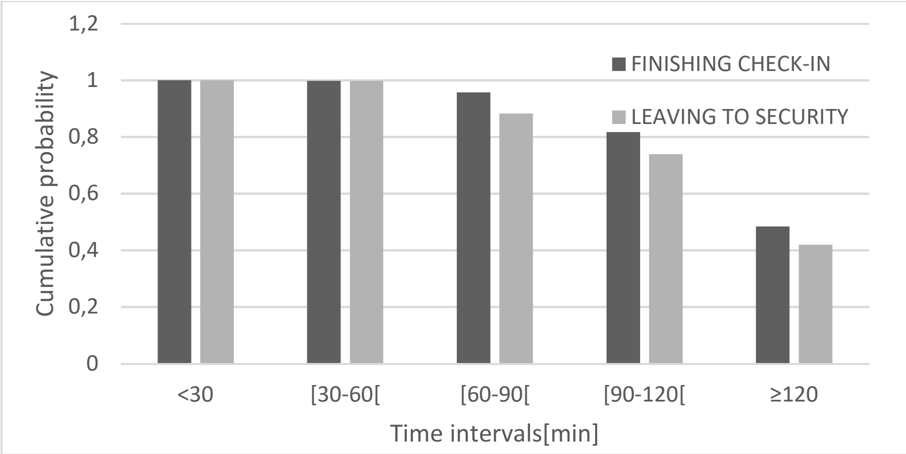


Figure 4.17 - Cumulative distribution for time left to board when: finishing check-in, or leaving to security.

81% of the passengers finish check-in with more than 90 minutes left to flight departure. When leaving to security 95% of the passengers have at least 47 minutes to proceed to security and then boarding. Passenger's dwell time mean is 21:40 minutes.

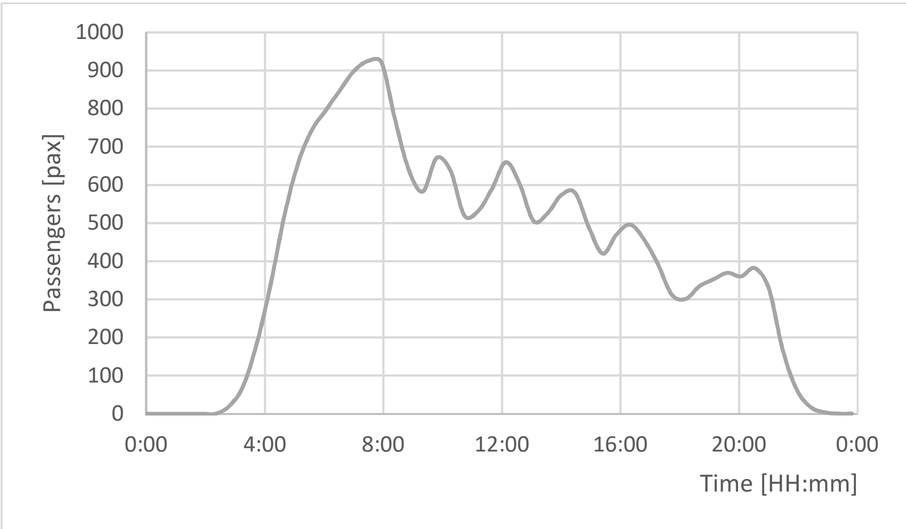


Figure 4.18 - Passenger daily distribution inside terminal.

When evaluating this scenario, it is clear to understand how the number of autonomous counters chosen is insufficient, and it starts to decrease terminal's performance as well as increasing passengers waiting time. The maximum number of passenger inside terminal increased when compared to other scenarios.

4.5 Discussion

A set of assumptions were made and explored to reach the objectives proposed by this dissertation. The validation of the base scenario resulted in realistic simulation with consistent data compared to what is expected. Also, software's animation contributed to understand the reliability of the model. The model was built with findings from literature. Concern in representation of distinct types of users with completely distinct decisions was achieved through an agent-based model. A prominent level of detail was given to the pedestrian and to its choices and interactions. The model successfully integrates: **(1)** distinct types of pedestrian that show different patterns of behaviors; **(2)** time pressure when choosing activities; **(3)** interaction with other pedestrians; and **(4)** interactions with the environment specially when introduced new check-in solutions. Although the results obtained from the base scenario met the expectations and fall inside statistical data collected from the airport the author would like to point some reasons that may affect results:

- Principles gathered from literature to represent pedestrian behavior were validated in respective models, yet the authors always pointed out how expensive it is to understand correctly the pedestrian behavior, and how it should be subject of better calibration. Though, all principles used were sufficient to represent, at this level, the pedestrian behavior and create realistic representation of the pedestrian.
- Check-in assignment was obtained through the means of observation in the airport, yet some operational rules change from airline to airline and from flight to flight, a simplification had to be made here. More, individual airlines' passengers have distinct needs to check-in baggage and to adopt web check-in.
- Passenger's arrival distribution was retrieved from Lisbon's airport terminal 1 and was assumed to be the same for all passengers although it is known passengers without hold-baggage have different patterns. Time pressure was assumed as linear and the thresholds used to represent the increase of time pressure may be subject of further analysis.
- Software limitations such as unreal representation of speed variation when arriving to the snake-queue lead to collisions, and some simulation runs (excluded from results) could leave an agent stuck in a corner or inside a wall.

Different passenger profiles with different perception of technology could affect passengers' waiting times resulting in more efficient terminal's operations (Figure 4.19). In this case when introducing self-service technologies i.e. full automated check-in counter. Improvements could lead to 74% reduction peak hour waiting time.

For each scenario, it was proposed a certain activation (which translates into a superior adoption if the solution is within passenger sight). For the first scenario, the same as kiosk attraction level seemed plausible as this autonomous self-service solution is similar to the kiosk and attracts the same type of passenger. Then, a growth in the activation level is to be expected with the introduction of this system in other airports. Passengers who have already used or are acquainted with the solution will be more inclined to use it i.e. increasing the interaction passenger-solution. The third solution is more of a hypothetical (for now) as most passengers may interact and proceed to the new solution.

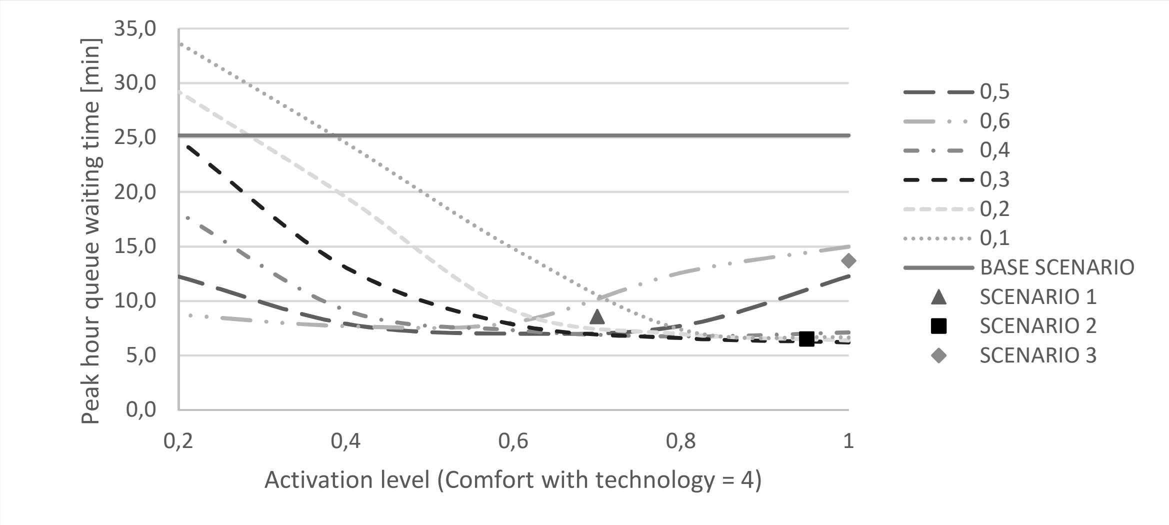


Figure 4.19 - Effect of activation on peak hour queue waiting time.

Detailed info on how interaction affects peak hour queue waiting time is found on Figure 4.20. The two passenger profiles (<u>comfort with tech = 4 on axis and comfort with tech = 1 on legend</u>) are explored over a parameters variation simulation to obtain the presented curves. Also, data collected from the three scenarios are presented as points. For lower activation rates, the peak hour waiting time reaches maximum values as the majority of the passengers keep using traditional counters.

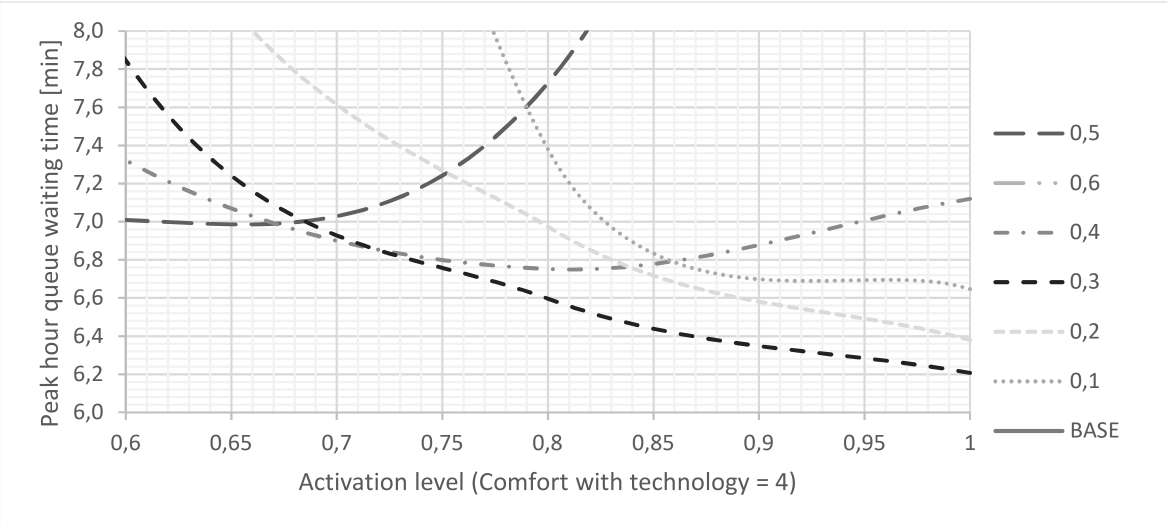


Figure 4.20 - Effect of activation (Detailed).

From results comparison, the first scenario was expected to have little significance on the results when compared to base scenario. However, the results show otherwise, it improves peak hour queue waiting time, having a variation of ▼61% meaning the actual kiosk attraction level could lead to great improvements in the terminal operations if fully automated technology were introduced. Second scenario with higher adoption rate improved the results from scenario 1 in

▼32% leading to what was expected as the solution that would bring the most benefits with the assumptions made. Last, the third scenario shows the saturation of the solution used with an increase of ▲110% when compared to scenario 2. More extensive data is shown in Table 4.10.

Table 4.10 - Results variations.

Variation	Parameters	Scenario 1	Scenario 2	Scenario 3
To base scenario	Peak hour queue waiting time	-61%	-74%	-45%
	Daily mean queue waiting time	-37%	-62%	-49%
To previous scenario	Peak hour queue waiting time	-	-32%	110%
	Daily mean queue waiting time	-	-40%	34%

Results confirm what is pointed in the literature, that self-service technology leads to improvements in the terminal: (1) less space is required for check-in; or (2) check-in capacity increases. In our base scenario, the passenger spends almost **50%** of their dwell time waiting in queues while in the best-case scenario the passenger would spend only **25%**. In terms of distribution inside terminal the use of fully automated counters led to a decrease on the landside area (Figure 4.21) and an increase on the time left to board. Passengers will be staying less time on the landside and more on the airside of the terminal.

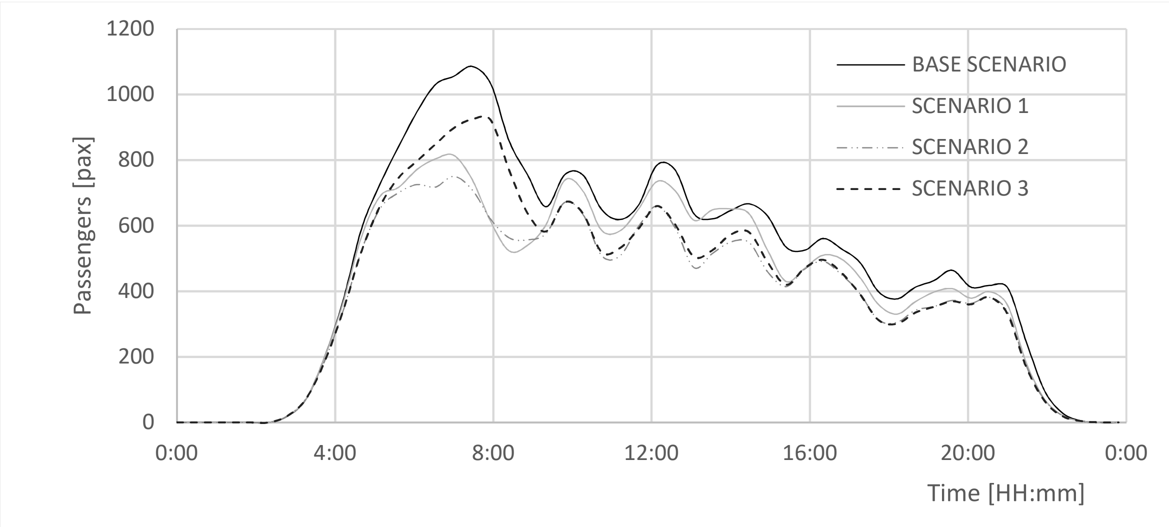


Figure 4.21 - Passenger daily distribution inside terminal.

Self-service counters lead to several improvements inside terminal. Some were explicitly showed such as improvements in waiting times and increase processing capacity. When integrating new systems inside the terminal, one should have in mind several passenger's categories and several interaction levels because the solution will only improve the system if adopted by the user.

4.6 Chapter review

This chapter demonstrated the application of an ABMS to the case study and the simulation of the integration of self-service technology. Lisbon's international airport terminal 1 was first introduced with all his characteristics. Some expected developments were studied, and it concluded the introduction of self-service baggage drop-off is to be expected in the short-term. To test that solution some scenarios were created. Scenarios creation strategy was related to findings in the literature: (1) however good a solution is, it only improves the system if the passenger recognizes value to it; and (2) interactions inside a terminal are of immense importance when evaluating the introduction of new elements.

After running the simulation model with a significant number of runs, the outputs were retrieved to provide insights about the model and the check-in solution. Results indicate that interactions have significant impact on terminal operations. The solution had different results for different levels of interaction. Yet, it was concluded the actual passenger experience with kiosk is enough to justify an investment in self-service baggage drop-off.

Experimental results indicate for each solution design, different level of interaction with the equipment could lead to under performance (over designed) from the system to the saturation of the system itself (under-design). Impact of interactions with newer solutions inside the terminal could improve the system.

Some model liabilities were found, and there is the need to improve the quality regarding passenger's behavior calibration. Essentially passenger behavior is found to have impact in the performance of the determined solution and therefore the performance of the terminal.

Chapter 5 – Conclusion

The fifth and last chapter of this dissertation is intended to conclude this research. It summarizes the areas covered, discusses his findings and how this research contributes to the knowledge of others. Future research direction will be recommended while limitations of this research are explored.

5.1 Conclusions

Nowadays, airports are becoming more focused on the passenger. Passengers determine if advanced technologies thrive inside the airports or not. Under this context, this research is motivated by the perception of the passenger to the inclusion of fully automated counters in the check-in process using an agent-based model.

The primary objective of this dissertation would be to develop an agent-based model to represent distinct passengers' profiles and assess terminal gains when more recent technology is applied to check-in area. By using the model to simulate pedestrian flow model inside Lisbon airport terminal, the influence on how passengers' profiles affect the performance of the solution was assessed and analyzed.

Literature review in chapter 2 revealed how different passenger's profiles are emerging in the airport, with different perceptions of technology and different requests. Also, in the check-in area the introduction of fully automated equipment seems to improve the system, but it is dependent of users' perception to those solutions. Modeling research indicates lack of research to include correct interactions in airport in order to reflect better the activity choice behavior.

Chapter 3 was focused on demonstrating the development of the model and all the underlying assumptions. In order to represent the pedestrian flow inside the terminal an agent-based model was developed. The model defines the pedestrian with basic traits and advanced characteristics that influence their behavior and activity choice. Also, it was implemented interaction with the environment and interaction with time reflecting time pressure.

Chapter 4 focused on applying the model to the case study which was Lisbon's international airport terminal 1. Some analysis was made to understand which would be the next development to terminal check-in and it was possible to conclude the introduction of fully automated machines would be the most realistic scenario following similar European airports' trend to introduce fully automated check-in. Three activation scenarios were proposed in order to simulate how distinct passenger profiles perceive and adopt newer solutions when presented to the passenger. The simulation results show how different passengers' profile feel attracted to technology differently and that could lead to different level of service inside the airport. Also, it was possible to conclude the actual positive perceive of the kiosk technology is enough to bring benefits when adopting fully automated counters. It was possible to understand how different passengers' profile can affect operations by observing and accepting the surroundings differently.

Aspects that this dissertation contribute the most are:

1. **Assess terminal operations improvements by introducing fully self-service check-in.**

The use of self-service technology is gaining ground in the check-in process. Fully automated counters enable passengers to drop their baggage drop-off in a fast process. Passengers seem to approve self-service technologies in diverse ways according to their profiles. Research finds how these innovative solutions are only able to improve the system if the user sees benefit in it and uses it. According to our research the levels of acceptance for the kiosk technology are enough to start integrate this automated system at the airports.

2. **Provide a more realistic agent-based model by incorporating interaction with terminal solutions inside the airport.**

An agent-based model was applied in this context because of its benefits in introducing passengers' characteristics and distinct behaviors for each profile. Also, previous model approaches failed to fully represent interactions with the environment. Models are becoming more and more complex, as a result, combining multiple model approaches into one simulation model is suggested. To support this statement, in the developed model, one can find agent-based mindset, while pedestrian movement is governed by a pedestrian-flow model.

Interactions with the environment is the most significant improvement of the proposed model. It was possible to represent impulsive actions in a complex model environment – the airport. Pedestrians in their model could, according to their profiles, interact with an object if presented within his range-view and feel attracted thus changing the previous decision.

3. **Reproduce influence of passenger's profiles on technology acceptance.**

Every passenger has its own profile, yet when related to technology acceptance there are patterns. Millennial and Generation Y seem to accept and be bolder to adopt newly solutions. Those differences affect the way a system works both operationally and economically, therefore one should carefully characterize the profiles they are working with.

An agent-based model is the best tool to reproduce passengers' profiles and behaviors. With the development of this tool, it is easy to adapt to other passengers' profiles to assess variations in the operational level. Introducing advanced traits such as comfort with technology enables the model to reproduce the influence of passengers' profiles on technology acceptance.

4. **Introduce possible application of agent-based pedestrian flow model**

Simulation is a powerful tool that provides the possibility to reproduce a real system. By having such possibility running scenarios can be tested providing results and insight information at little cost. Those results can be used from the airport design to the management perspective i.e. design changes, allocate optimal resource, measure peak capacity and analyze effectiveness of airport processing facilities.

Other environments (e.g. railway stations and shopping malls) are perfect environments for the application of an agent-based model.

5.2 Research limitations and future research recommendations

After the conclusion of this research it is possible to understand many of the liabilities reside in the lack of access to accurate data to model the airport. This leads to difficulties in model validation and in simplified assumptions while modeling. Also, the accuracy of the decision-making process of humans determines the reliability of an agent-based model. Others have explored agent-based models in airports, (e.g. how basic traits correlate to passenger's behavior) however, lack of access empirical data results in oversimplified assumptions. Additionally, this model tried to resolve this issue by validate and use previous validated assumptions from other authors, yet some assumptions were oversimplified. Therefore, the most limitation of this research was the access airport passengers' characteristics data and to airport data itself to further validate the model. Regarding these points future research could be undertaken in the following areas:

1. Collect data regarding passengers' characteristics

Pedestrian characteristics influence the decision-making process inside the terminal. Since the environment where the passenger is affects their behavior, it is necessary to collect detailed data from the reference environment. This was a more realistic model can be build. Basic pedestrian traits (e.g. age, gender, nationality, etc.) correlate to more advanced traits with the pedestrian status (e.g. time pressure, arrival pattern distribution).

Understand further the passengers' characteristics, creates more detailed passengers' profiles and, enables a more accurate representation of motivations and behavior patterns find in each profile.

2. Explore motivations of the passengers to adopt innovative solutions in airports

There is continuous development in airport terminals, and the adoption rates may differ from passenger to passenger, understanding what motivates certain type of passengers to adopt such solution enables correct interpretation to output gather from simulations. Also, as was showed by this research, interactions while on the airport could lead to improvements, therefore it shows great advantage to understand what motivated the passengers to change the previous chosen method.

Factors such as system reliability, perception or other ways to attract (e.g. situate agents showing the system or imposing fines) relate to the passengers' characteristics to adopt and feel attracted by the advanced systems.

3. Investigate the application of agent-based pedestrian flow model

Other applications for the agent-based model are possible so it is worthy to investigate other applications. Modeling is a tool to be used to assess terminal gains or losses and to define other strategies such as: proposing regulation or testing the level of service (LOS) or designing new airports. Also, this model can be used in other environments, such as rail stations, malls or streets with proper adaptations.

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Appendices

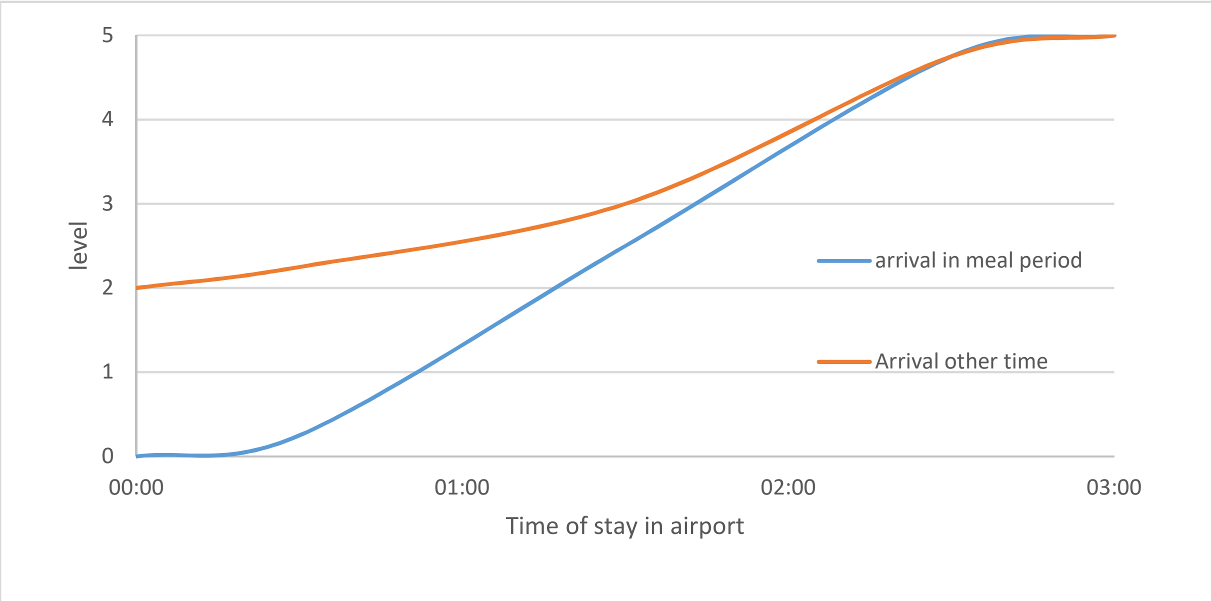
A. Parameters for simulation

Bayesian Rules

Comfort with technology				
Frequency of travel	Less than 3		More than 3	
Age	Less 65	Over 65	Less 65	Over 65
Level	1	0	4	1

Eagerness to shop								
Gender	Male				Female			
Nationality	Native		Foreigner		Native		Foreigner	
Frequency of travel	Less than 3	More than 3	Less than 3	More than 3	Less than 3	More than 3	Less than 3	More than 3
Level	2	3	1	3	5	4	5	5

Hunger Level



Inputs for model:

Data	Value
Low-int Schengen	0,2
Low-int non-Schengen	0,25
Med-int Schengen	0,6
Med-in non-Schengen	0,6
High-int Schengen	0,2
High-int non-Schengen	0,15
Male	0,65
Female	0,35
Age<31	0,25
Age<41	0,54
Age<56	0,82
Age<66	0,95
Age>0	1
Trav Freq<3	0,53
Nationals?	0,43
Trav Purp business?	0,5

Flight info

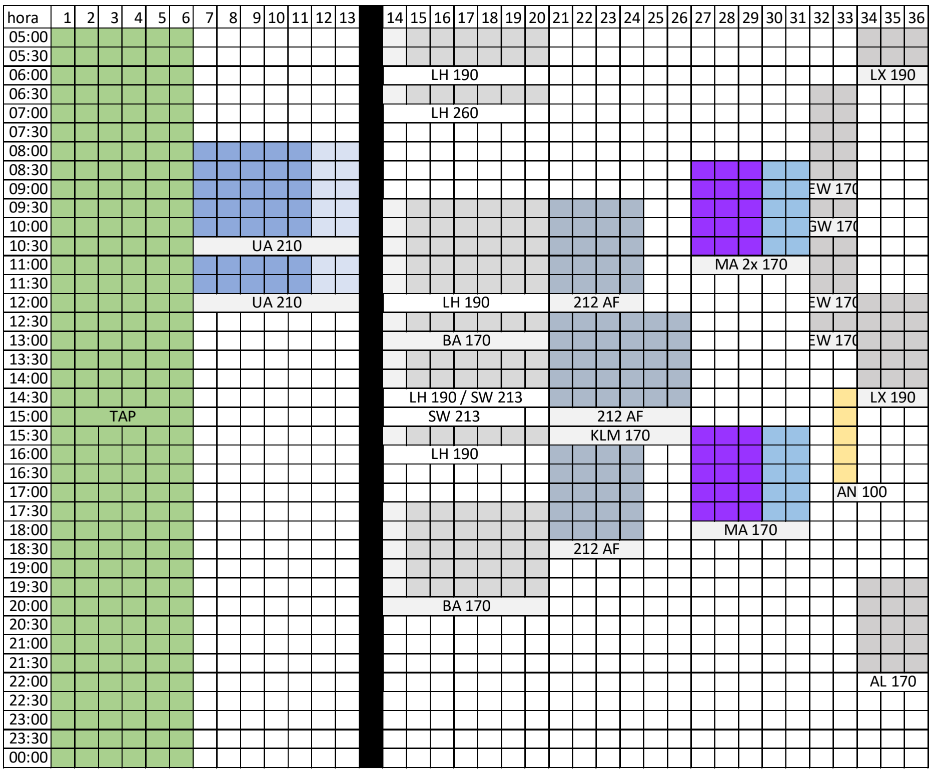
date	dest	company	economic	business	Schengen	Counter ECO	counter business	boarding	Bag-tag
10/5/17 6:00	Luxembourg (LUX)	Luxair	148	0	True	11		False	False
10/5/17 6:05	Munich (MUC)	Lufthansa	128	24	True	4	5	True	False
10/5/17 6:30	Ponta Delgada (PDL)	Azores Airlines	163	14	True	20	21	True	False
10/5/17 6:35	Paris (ORY)	TAP Portugal	93	12	True	22	0	True	True
10/5/17 6:45	Barcelona (BCN)	TAP Portugal	115	9	True	22	0	True	True
10/5/17 6:45	Frankfurt (FRA)	TAP Portugal	93	12	True	22	0	True	True
10/5/17 6:50	Rome (FCO)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 6:55	Madrid (MAD)	TAP Express	80	4	True	22	0	True	True
10/5/17 7:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 7:05	Copenhagen (CPH)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 7:05	London (LGW)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 7:05	Milan (MXP)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 7:05	Oslo (OSL)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 7:15	Frankfurt (FRA)	Lufthansa	180	33	True	4	5	True	False
10/5/17 7:25	Madrid (MAD)	Air Europa	86	0	True	24		False	False
10/5/17 7:25	London (LHR)	British Airways	76	38	True	12	13	True	False
10/5/17 7:30	Brussels (BRU)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 7:30	Venice (VCE)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 7:40	Lajes (TER)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 7:40	London (LHR)	TAP Portugal	200	16	True	22	0	True	True
10/5/17 7:45	Funchal (FNC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 7:45	Guarulhos (GRU)	TAP Portugal	185	28	False	22	0	True	True
10/5/17 7:55	Bordeaux (BOD)	TAP Express	80	4	True	22	0	True	True
10/5/17 8:00	Horta (HOR)	Azores Airlines	109	17	True	20	21	True	False
10/5/17 8:00	Lajes (TER)	Azores Airlines	109	17	True	20	21	True	False
10/5/17 8:00	São Vicente (VXE)	TACV	168	0	False	25		False	False
10/5/17 8:00	A Coruna (LCG)	TAP Express	56	0	True	22	0	True	True
10/5/17 8:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 8:00	Paris (ORY)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 8:00	Vienna (VIE)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 8:10	Marseille (MRS)	TAP Express	80	4	True	22	0	True	True
10/5/17 8:15	Malaga (AGP)	TAP Express	56	0	True	22	0	True	True
10/5/17 8:20	Valencia (VLC)	TAP Express	56	0	True	22	0	True	True
10/5/17 8:20	Hamburg (HAM)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 8:30	Lyon (LYS)	TAP Express	80	4	True	22	0	True	True
10/5/17 8:30	Frankfurt (FRA)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 8:30	Geneva (GVA)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 8:30	Rio de Janeiro (GIG)	TAP Portugal	200	16	False	22	0	True	True

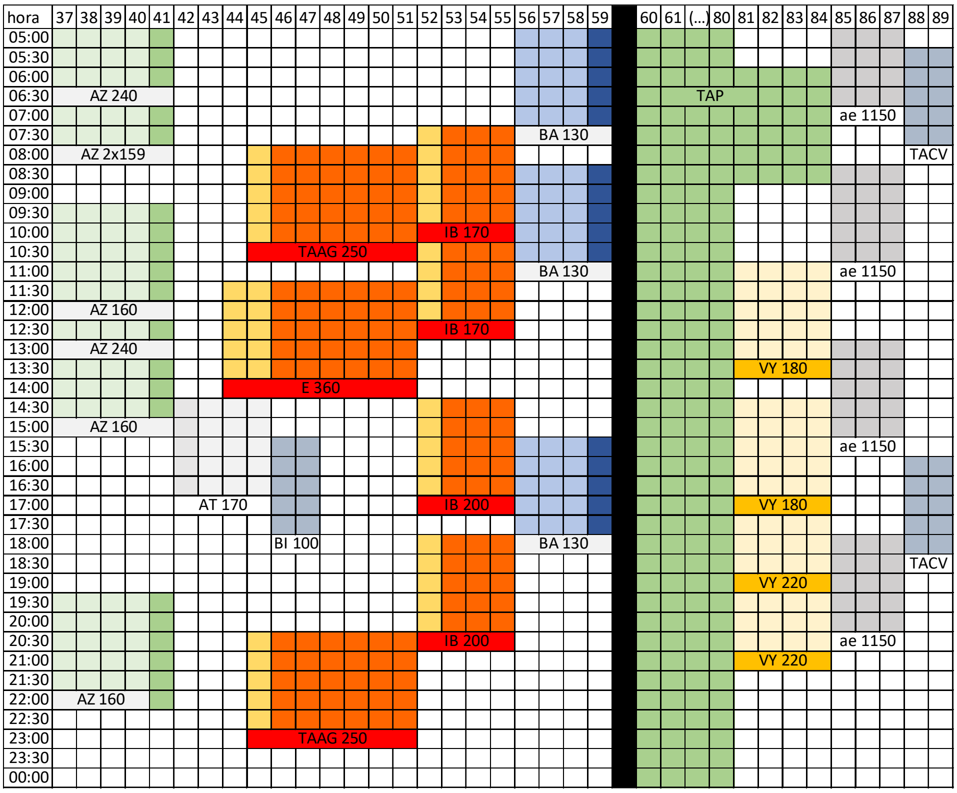
10/5/17 8:40	Dusseldorf (DUS)	TAP Express	80	4	True	22	0	True	True
10/5/17 8:45	Stuttgart (STR)	Eurowings	135	0	True	10		False	False
10/5/17 8:50	Munich (MUC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 9:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 9:00	Barcelona (BCN)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 9:00	Rome (FCO)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 9:00	Amsterdam (AMS)	TAP Portugal	91	33	True	22	0	True	True
10/5/17 9:00	Barcelona (BCN)	Vueling	144	0	True	26		False	False
10/5/17 9:00	Zurich (ZRH)	Vueling	144	0	True	26		False	False
10/5/17 9:05	Toulouse (TLS)	TAP Express	80	4	True	22	0	True	True
10/5/17 9:05	Milan (MXP)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 9:20	Zurich (ZRH)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 9:25	Madrid (MAD)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 9:25	Praia (RAI)	TAP Portugal	89	16	False	22	0	True	True
10/5/17 9:30	Faro (FAO)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 9:30	Funchal (FNC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 9:35	Brasilia (BSB)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 9:35	Brussels (BRU)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 9:40	Stuttgart (STR)	Germanwings	115	0	True	10		False	False
10/5/17 9:40	Belo Horizonte (CNF)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 9:45	Accra (ACC)	TAP Portugal	107	17	False	22	0	True	True
10/5/17 9:50	Madrid (MAD)	Iberia	99	40	True	14	15	True	False
10/5/17 9:55	Paris (ORY)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 10:00	Marrakesh (RAK)	TAP Express	80	4	False	22	0	True	True
10/5/17 10:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 10:05	London (LHR)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 10:25	New York (EWR)	United Airlines	148	23	False	2	3	True	True
10/5/17 10:40	Birmingham (BHX)	Monarch Airlines	139	0	True	8	9	False	False
10/5/17 10:40	Manchester (MAN)	Monarch Airlines	171	0	True	8	9	False	False
10/5/17 10:45	Boston (BOS)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 10:55	Barcelona (BCN)	TAP Express	80	4	True	22	0	True	True
10/5/17 10:55	Ponta Delgada (PDL)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 11:00	Luanda (LAD)	TAAG Angola Airlines	152	52	False	16	17	True	False
10/5/17 11:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 11:10	London (LHR)	British Airways	76	38	True	12	13	True	False
10/5/17 11:15	Dublin (DUB)	Aer Lingus	139	0	True	32		False	False
10/5/17 11:15	Sao Paulo (GRU)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 11:25	Madrid (MAD)	Air Europa	86	0	True	24		False	False
10/5/17 11:30	Istanbul (IST)	Turkish Airlines	140	9	False	33	34	True	False
10/5/17 11:40	Cologne (CGN)	Eurowings	135	0	True	10		False	False
10/5/17 11:50	Campinas (VCP)	Azul Linhas Aereas	200	16	False	26	27	False	False
10/5/17 12:00	Horta (HOR)	Azores Airlines	109	17	True	20	21	True	False
10/5/17 12:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 12:10	Paris (CDG)	Air France	169	0	True	6	7	True	False
10/5/17 12:10	Frankfurt (FRA)	Lufthansa	128	24	True	4	5	True	False
10/5/17 12:10	Funchal (FNC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 12:15	Philadelphia (PHL)	American Airlines	128	13	False	28	29	True	False
10/5/17 12:15	Washington (IAD)	United Airlines	86	47	False	2	3	True	True
10/5/17 12:20	London (LHR)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 12:20	Madrid (MAD)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 12:25	Seville (SVQ)	TAP Express	56	0	True	22	0	True	True
10/5/17 12:30	Paris (ORY)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 12:30	Rome (FCO)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 12:35	Madrid (MAD)	Iberia	99	40	True	14	15	True	False
10/5/17 12:35	Stockholm (ARN)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 12:40	Brussels (BRU)	Brussels Airlines	129	9	True	4	5	True	False
10/5/17 12:45	Cologne (CGN)	Eurowings	135	0	True	10		False	False
10/5/17 12:45	Vigo (VGO)	TAP Express	56	0	True	22	0	True	True
10/5/17 12:45	New York (EWR)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 12:50	Toronto (YYZ)	Air Canada Rouge	175	48	False	30	31	True	False
10/5/17 12:50	Ponta Delgada (PDL)	Azores Airlines	163	14	True	20	21	True	False
10/5/17 13:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 13:00	Vienna (VIE)	TAP Portugal	200	16	True	22	0	True	True
10/5/17 13:20	Barcelona (BCN)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 13:30	Luxembourg (LUX)	Luxair	148	0	True	11		False	False
10/5/17 13:30	Bologna (BLQ)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 13:35	Amsterdam (AMS)	Vueling	144	0	True	23		False	False
10/5/17 13:50	Casablanca (CMN)	TAP Express	56	0	False	22	0	True	True
10/5/17 14:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 14:05	Toronto (YYZ)	Air Canada Rouge	268	51	False	30	31	True	False
10/5/17 14:05	Amsterdam (AMS)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 14:10	Nice (NCE)	TAP Express	80	4	True	22	0	True	True
10/5/17 14:15	Dubai (DXB)	Emirates	248	40	False	16	17	False	False
10/5/17 14:20	Manchester (MAN)	TAP Express	80	4	True	22	0	True	True
10/5/17 14:25	Munich (MUC)	Lufthansa	128	24	True	4	5	True	False
10/5/17 14:25	Lyon (LYS)	TAP Express	80	4	True	22	0	True	True
10/5/17 14:30	Zurich (ZRH)	Swiss	160	9	True	4	5	False	False

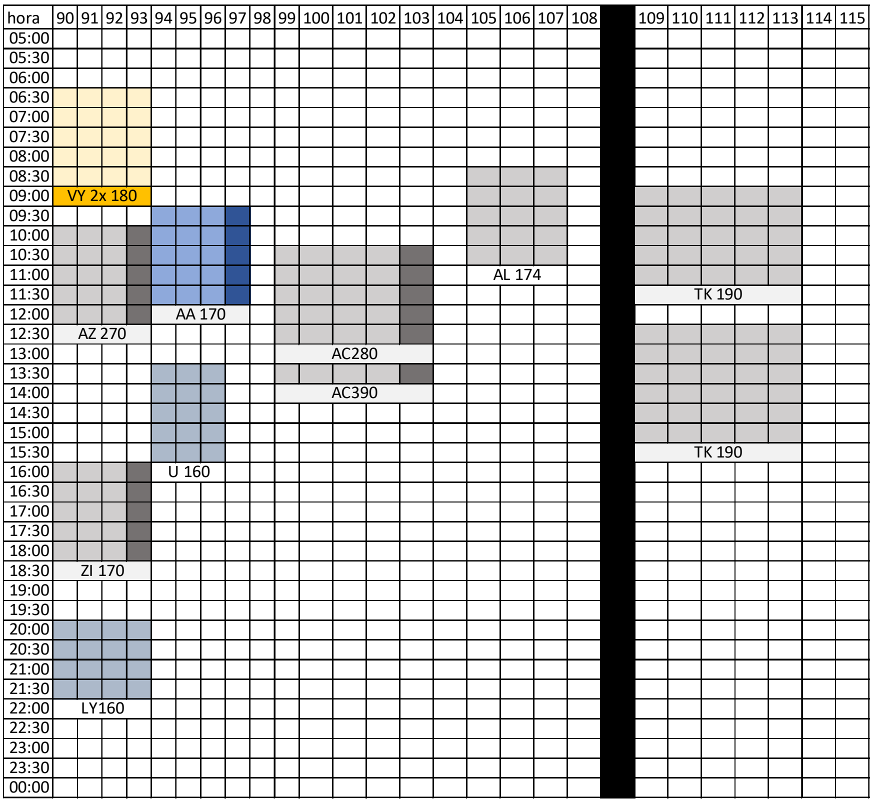
10/5/17 14:30	Brussels (BRU)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 14:30	Frankfurt (FRA)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 14:30	Zurich (ZRH)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 14:35	Paris (ORY)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 14:40	Luxembourg (LUX)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 14:40	Milan (MXP)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 14:45	Nantes (NTE)	TAP Express	80	4	True	22	0	True	True
10/5/17 14:55	Munich (MUC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 15:00	Santa Maria (SMA)	Azores Airlines	109	17	False	20	21	True	False
10/5/17 15:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 15:05	Geneva (GVA)	Swiss	100	28	True	4	5	False	False
10/5/17 15:05	London (LHR)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 15:20	Funchal (FNC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 15:35	Amsterdam (AMS)	KLM	120	16	True	6	7	True	False
10/5/17 15:40	Rome (FCO)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 15:45	Madrid (MAD)	Air Europa	84	0	True	24		False	False
10/5/17 15:45	Istanbul (IST)	Turkish Airlines	108	12	False	33	34	True	False
10/5/17 15:50	Paris (CDG)	Air France	169	0	True	6	7	True	False
10/5/17 15:55	Madrid (MAD)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 16:00	Geneva (GVA)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 16:00	Porto (OPO)	TAP Portugal	56	0	True	1	0	True	True
10/5/17 16:05	Moscow (DME)	Ural Airlines	128	0	False	28		False	False
10/5/17 16:10	Frankfurt (FRA)	Lufthansa	128	24	True	4	5	True	False
10/5/17 16:10	Barcelona (BCN)	TAP Express	80	4	True	22	0	True	True
10/5/17 16:10	Toulouse (TLS)	TAP Express	80	4	True	22	0	True	True
10/5/17 16:10	London (LHR)	TAP Portugal	91	33	True	22	0	True	True
10/5/17 16:25	Paris (ORY)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 16:30	Asturias (OVD)	TAP Express	56	0	True	22	0	True	True
10/5/17 16:40	Madrid (MAD)	Iberia	129	22	True	14	15	True	False
10/5/17 16:40	Salvador (SSA)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 16:50	Recife (REC)	TAP Portugal	185	28	False	22	0	True	True
10/5/17 17:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 17:00	Copenhagen (CPH)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 17:00	Fortaleza (FOR)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 17:00	New York (JFK)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 17:00	Zurich (ZRH)	Vueling	144	0	True	23		False	False
10/5/17 17:10	Casablanca (CMN)	Royal Air Maroc	117	9	False	18	19	True	False
10/5/17 17:15	Santander (SDR)	Air Nostrum	80	0	False	10		False	False
10/5/17 17:15	Madrid (MAD)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 17:30	Funchal (FNC)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 17:35	Prague (PRG)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 18:00	Las Palmas (LPA)	Binter Canarias	80	0	False	16		False	False
10/5/17 18:00	Hamburg (HAM)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 18:00	Porto (OPO)	TAP Portugal	56	0	True	1	0	True	True
10/5/17 18:10	Frankfurt (FRA)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 18:10	Paris (ORY)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 18:15	London (LGW)	Monarch Airlines	139	0	True	8	9	False	False
10/5/17 18:15	Berlin (TXL)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 18:25	Natal (NAT)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 18:30	Paris (ORY)	Aigle Azur	139	0	True	26		False	False
10/5/17 18:30	Praia (RAI)	TACV	168	0	False	25		False	False
10/5/17 18:35	Paris (CDG)	Air France	169	0	True	6	7	True	False
10/5/17 18:45	Barcelona (BCN)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 18:50	London (LHR)	British Airways	76	38	True	12	13	True	False
10/5/17 19:00	Amsterdam (AMS)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 19:00	Porto (OPO)	TAP Portugal	56	0	True	1	0	True	True
10/5/17 19:05	London (LHR)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 19:05	Paris (ORY)	Vueling	176	0	True	23		False	False
10/5/17 19:15	Funchal (FNC)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 19:20	Bissau (OXB)	TAP Portugal	89	16	False	22	0	True	True
10/5/17 19:20	Munich (MUC)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 19:40	Madrid (MAD)	Air Europa	84	0	True	24		False	False
10/5/17 19:40	Paris (ORY)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 19:40	Rome (FCO)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 19:45	Brussels (BRU)	Brussels Airlines	112	0	True	4		True	False
10/5/17 19:55	Brussels (BRU)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 20:00	Porto (OPO)	TAP Express	56	0	True	1	0	True	True
10/5/17 20:15	Geneva (GVA)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 20:15	London (LHR)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 20:30	Bilbao (BIO)	TAP Portugal	56	0	True	22	0	True	True
10/5/17 20:35	Madrid (MAD)	Iberia	129	22	True	14	15	True	False
10/5/17 20:40	Valencia (VLC)	TAP Express	56	0	True	22	0	True	True
10/5/17 20:45	Milan (MXP)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 20:45	Nice (NCE)	TAP Portugal	80	4	True	22	0	True	True
10/5/17 20:50	Toulouse (TLS)	TAP Portugal	80	4	True	22	0	True	True
10/5/17 20:55	Toulouse (TLS)	TAP Portugal	80	4	True	22	0	True	True
10/5/17 21:00	Barcelona (BCN)	TAP Portugal	89	16	True	22	0	True	True

10/5/17 21:00	Porto (OPO)	TAP Portugal	56	0	True	1	0	True	True
10/5/17 21:05	Barcelona (BCN)	Vueling	176	0	True	23		False	False
10/5/17 21:20	Malaga (AGP)	TAP Portugal	56	0	True	22	0	True	True
10/5/17 21:25	Funchal (FNC)	TAP Portugal	91	33	True	22	0	True	True
10/5/17 21:35	Madrid (MAD)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 21:45	Seville (SVQ)	TAP Express	56	0	True	22	0	True	True
10/5/17 21:50	Praia (RAI)	TAP Portugal	107	17	False	22	0	True	True
10/5/17 21:55	Ponta Delgada (PDL)	Azores Airlines	109	17	True	20	21	True	False
10/5/17 21:55	Dakar (DKR)	TAP Portugal	147	17	False	22	0	True	True
10/5/17 21:55	Ponta Delgada (PDL)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 22:00	Espargos (SID)	TAP Portugal	89	16	False	22	0	True	True
10/5/17 22:00	Porto (OPO)	TAP Portugal	80	4	True	22	0	True	True
10/5/17 22:10	Tel Aviv (TLV)	El Al	110	12	False	26	27	False	False
10/5/17 22:15	Algiers (ALG)	TAP Portugal	80	4	False	22	0	True	True
10/5/17 22:20	Dublin (DUB)	Aer Lingus	139	0	True	11		False	False
10/5/17 22:30	Ponta Delgada (PDL)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 23:00	Luanda (LAD)	TAAG Angola Airlines	152	52	False	16	17	True	False
10/5/17 23:00	Moscow (DME)	TAP Portugal	107	17	False	22	0	True	True
10/5/17 23:05	Faro (FAO)	TAP Portugal	107	17	True	22	0	True	True
10/5/17 23:05	Funchal (FNC)	TAP Portugal	89	16	True	22	0	True	True
10/5/17 23:15	Porto (OPO)	TAP Portugal	147	17	True	22	0	True	True
10/5/17 23:20	Luanda (LAD)	TAP Portugal	185	28	False	22	0	True	True
10/5/17 23:30	Rio de Janeiro (GIG)	TAP Portugal	200	16	False	22	0	True	True
10/5/17 23:30	Sao Paulo (GRU)	TAP Portugal	185	28	False	22	0	True	True

Counter Schedule




hora
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
60 61 (...) 80 81 82 83 84 85 86 87 88 89
05:00 05:30 06:00 06:30 07:00 07:30 08:00 08:30 09:00 09:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 00:00
AZ 240
TAP
ae 1150
BA 130
TACV
AZ 2x159
IB 170
TAAG 250
BA 130
ae 1150
AZ 160
IB 170
AZ 240
VY 180
E 360
AZ 160
ae 1150
AT 170
IB 200
VY 180
BI 100
BA 130
TACV
VY 220
IB 200
ae 1150
VY 220
AZ 160
TAAG 250


hora
90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108
109 110 111 112 113 114 115
05:00 05:30 06:00 06:30 07:00 07:30 08:00 08:30 09:00 09:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 00:00
VY 2x 180
AL 174
TK 190
AA 170
AZ 270
AC280
AC390
TK 190
U 160
ZI 170
LY160

B. Simulation Functions

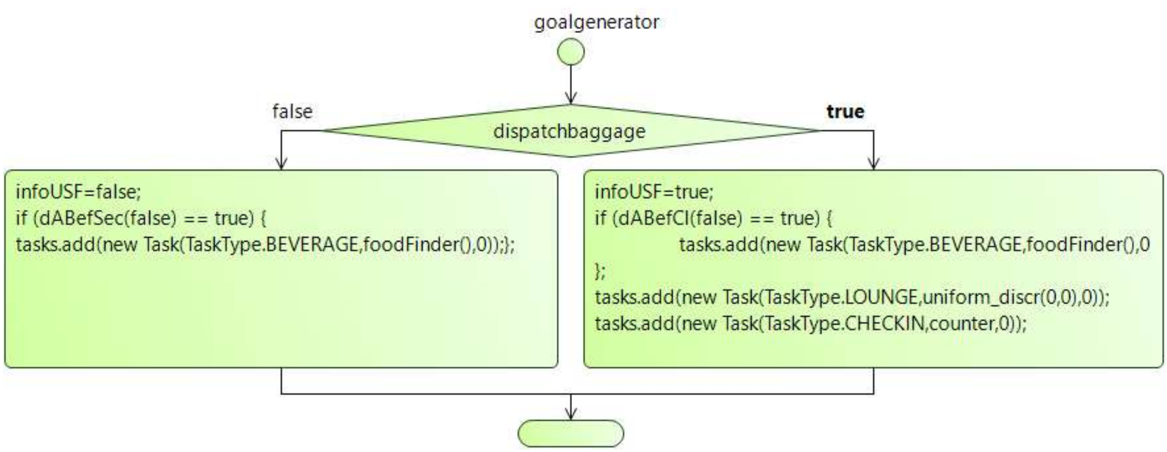
Inject pax

```
updateRate();
economicSource.set_rate( rateEconomic );
businessSource.set_rate( rateBusiness );

function updateRate ()
{
	double t = dateToTime( date_ ) - time();
	if ( t <= 220 * 60 && t > 60 * 160) {
		double rtEco = schengen ? main.low_int_Schengen * economic * 1.0 /
		60 : main.low_int_non_Schengen * economic * 1.0 / 60;
		rateEconomic = 1 / rtEco;
		double rtBus = schengen ? main.low_int_Schengen * business * 1.0 /
		60 : main.low_int_non_Schengen * business * 1.0 / 60;
		rateBusiness = 1 / rtBus;

	};
	if ( t <= 60 * 160 && t > 60 * 100) {
		double perc = Schengen ? main.low_int_Schengen :
		main.low_int_non_Schengen;
		double rtEco = (perc * economic - economicSource.count() +
		main.med_int_non_Schengen * economic) * 1.0 / 60;
		rateEconomic=1/rtEco;
		double rtBus = (perc * business - businessSource.count() +
		main.med_int_Schengen * business) * 1.0/60;
		rateBusiness = 1 / rtBus;
	};

	if ( t <= 60 * 100 && t > 60 * 40) {
		double perc = schengen? main.low_int_Schengen +
		main.med_int_Schengen : main.low_int_non_Schengen +
		main.med_int_non_Schengen;
		double ecorem = perc * economic - economicSource.count();
		double busrem = perc * business - businessSource.count();
		double rtEco = (schengen) ? (ecorem+main.high_int_Schengen *
		economic) * 1.0 / 60 : (ecorem + main.high_int_non_Schengen *
		economic) * 1.0 / 60;
		rateEconomic = 1 / rtEco;
		double rtBus = (schengen) ? (busrem+main.high_int_Schengen *
		business) * 1.0 / 60 : (busrem + main.high_int_non_Schengen *
		business) * 1.0/60;
		rateBusiness=1/rtBus;

	};
};
```

PedGeneration

```
if ( probAge <= main.age_31 ) {
      age = 1;
      velAge = 1.46;
      stdAge1 = 0.22;
};
if ( probAge > main.age_31 && probAge <= main.age_41 ){
      age = 2;
      velAge = 1.49;
      stdAge1 = 0.23;
};
if ( probAge > main.age_41 && probAge <= main.age_56 ){
      age = 3;
      velAge = 1.49;
      stdAge1 = 0.23;
};
if ( probAge > main.age_56 && probAge <= main.age_66 ){
      age = 4;
      velAge = 1.37;
      stdAge1 = 0.28;
};
if ( probAge > main.age_66 && probAge <= main.age_0 ){
      age = 5;
      velAge = 1.37;
      stdAge1 = 0.28;
};
counter = business ? flight.counterBusiness : flight.counterEconomic;
travelFreq = ( probTravFreq <= main.travFreq ) ? 1 : 2;
portuguese = ( probNationality <= main.national ) ? true : false;
travelPurpBus = ( probTravPurp <= main.travPurp ) ? true : false;
male = ( probGender <= main.male ) ? true : false;
velGender = male ? 1.4 : 1.27;
stdGender1 = male ? 0.22 : 0.22;
velPurp = travelPurpBus ? 1.36 : 1.00;
stdPurp1 = travelPurpBus ? 0.22 : 0.23;

velocityMean = (velAge + velGender + velPurp) / 3.0;
velocitySTD = sqrt((stdAge1 * stdAge1 + stdGender1 * stdGender1 + stdPurp1 *
stdPurp1)) / 3.0;
```

Goal generator



Determine activation automated drop-off

```
kiosk=null;
if(comWTech == 0) probKiosk = main.act0;
if(comWTech == 1) probKiosk = main.act1;
if(comWTech == 4) probKiosk = main.act4;
for ( Kiosk k  : agentsInRange(main.kiosk,15,METER) ) {
	if(kiosks.contains(k)){ } else {
		if ( k.waiting < 4 ) { // decision
			probKiosk = k.waiting <= 2 ? // queue length affecting
			probKiosk : - probKiosk*k.waiting*0,5 + 2*probKiosk;
			if ( randomTrue(probKiosk) ) {
				kiosk=k;
				kioskACT=true;
				kiosks.add(k);
			} else {
				kioskUSF = false;
			};
		};
	};
};
return kiosk ;
```

Determine store/food probability before check-in under time stress

```
function daBefCI (boolean retail)
{
	double[] probRetail = { 0.06 , 0.08 , 0.10 , 0.12 , 0.14 };
	double[] probFood = { 0.20 , 0.22 , 0.24 , 0.25 , 0.30 };
	double prob[] = retail? probRetail : probFood;
	double t = time();
	double std = dateToTime( flight.date_);
	p2 = prob[eggToShop-1];
	p2 = std - t > 180 * 60 ? p2 : - p2 * (t - std) / (90*60) - p2;
	p2 = p2 < 0 ? 0 : p2;
	return ( p2 );

};
```

Determine store/food probability before security under time stress

```
function daBefSec (boolean retail)
{
	double[] probRetail = { 0.06 , 0.08 , 0.10 , 0.12 , 0.14 };
	double[] probFood = { 0.20 , 0.22 , 0.24 , 0.26 , 0.28 };
	double prob[] = retail? probRetail : probFood;
	double t = time();
	double std = dateToTime( flight.date_);
	p1 = prob[eggToShop-1];
	p1 = std - t > 120 * 60 ? p1 : - p1 * (t - std) / (90*60) - p1 / 3;
	p1 = p1 < 0 ? 0 : p1;
	return ( p1 );
};
```

Determine activation info

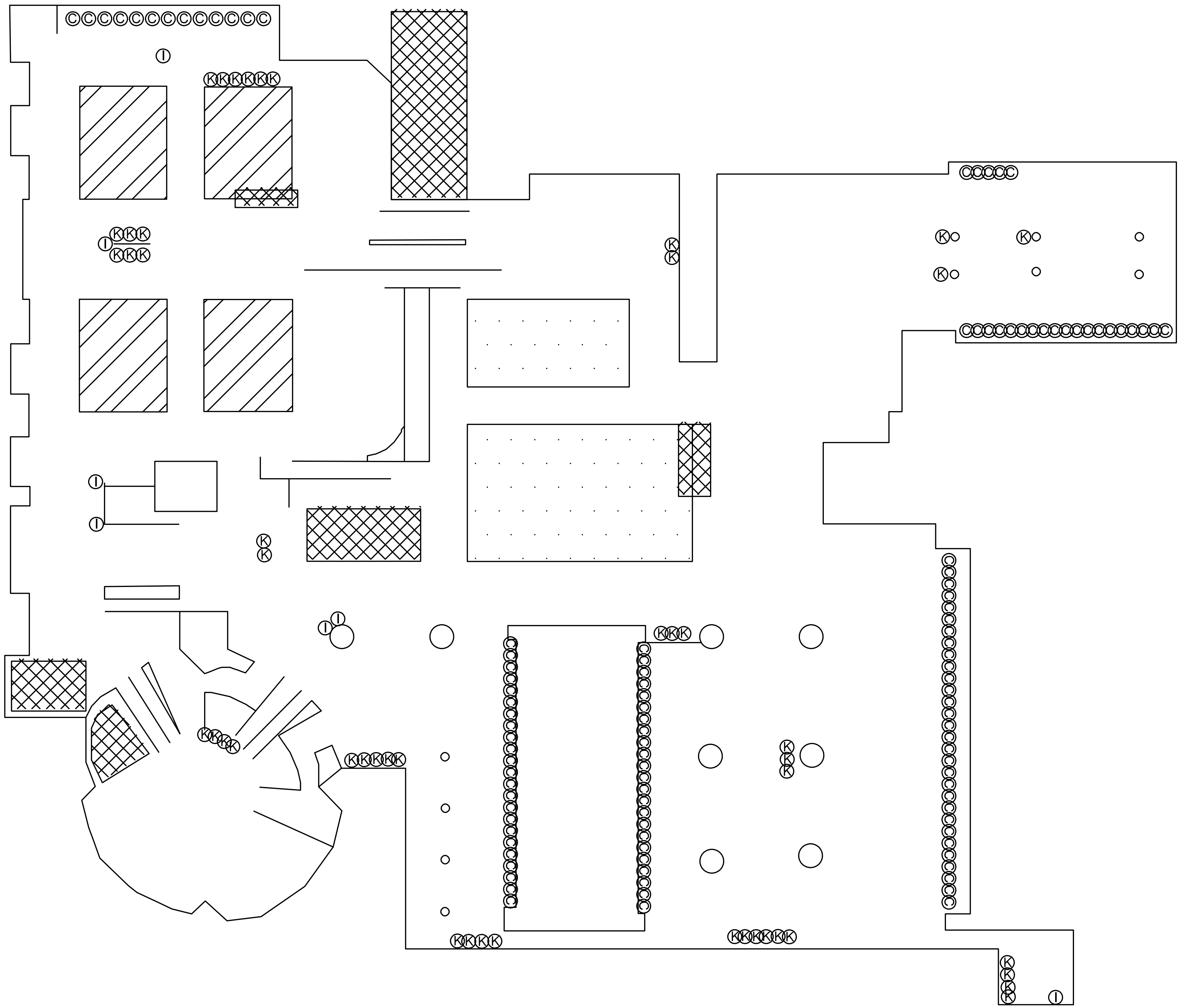
```
info=null;
for (Info i : agentsInRange ( main.info, 15 ,METER ))
	{
		info=i;
		infoACT=true;
	};
return info;
```

Determine activation Stores

```
retail = null;
for ( Reatil r  : agentsInRange(main.retail, 15 ,METER) ) {
      if(retails.contains(r)){ } else {
             probRetail = checkIn? daBefCI (true) : daBefSec (true);
             probRetail = - probRetail * r.occupancy + probRetail;
             if ( randomTrue(probRetail) ) {
                   retail=r;
                   retailACT=true;
                   retails.add(r);
             } else {
                   retailUSF = false;
             };
        };
 };
 return retail ;
```

x

C. Blueprints



Captation	
Ⓒ	Counter
Ⓘ	Info point
Ⓚ	Kiosk
(diagonal hatch)	Retail
(cross hatch)	Food
(dotted)	Support

Técnico Lisboa	Lisbon airport blueprint		Date: March-2018
Degree: Mestrado Eng. Civil	Name: Cláudio Miguel Costa Esteves	Number: 73623	Scale: 1:750
			Numer: 1.0