Master's Thesis

MASTER'S DEGREE IN INDUSTRIAL ENGINEERING

Improving Check-in Processing at Brisbane Airport

REPORT

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Date: September 2017

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ABSTRACT

It is concerned that current designs in airport terminals need to be adaptable in terms of time and cost increasing their capacity to be able to meet demand.

The terminal functionality is limited for some issues in the system's performance as queues or delays, affecting the quality perceived by the passengers about the provided service. According to current research, the check-in area is considered the bottleneck in the facilities of the terminal. Consequently, the system needs to be reconfigured to improve its operation.

Passengers can chose the traditional manual check-in at the counter or self-service automatic kiosk and bag drop. In this project, real-time information system will be provided using passenger throughput information to create flow path simulation for the domestic terminal in the Brisbane Airport.

By building the simulation model, the system's structure will be explored and the behaviour tested under a variety of conditions to play and compare scenarios to optimize the procedure.

Ultimately, renovations will be made to the facility with the aim to minimize average dwell time and improve overall customer satisfaction.

The ability to react quickly to the increasing passenger fluctuations with rapid and inexpensive changes in the check-in configuration would be the major contribution of the thesis. The strategy presented as a solution for a real world problem supports the adaptation of check-in facilities to the different dynamic environments in other airports.

Key Words: Airport, Check-In, Simulation, Kiosk, Manual, Waiting time.

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GLOSSARY

BAC – Brisbane Airport Corporation

CU – Common User

KPI – Key Performance Indicator

ST – Service Time

TBA – Time Between Arrivals

UQ – University of Queensland

VA – Virgin Australia

WT – Waiting Time

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1. PREFACE

1.1   Origins

This project was born from the need of the Airport to have a new point of view about the domestic terminal that could help them to change the configuration of the terminal with the main objective of increasing customer satisfaction.

The University of Queensland (UQ) is one of Australia's leading researches and teaching institutions, ranked well inside the world's top 100 by the Times Higher Education rankings and much of this work has been conducted in collaboration with global partners.

As the University of Queensland had already participated in another projects with the airport, the BAC decided to give this opportunity to the students that had recently graduated. They will have to focus on quality management, process improvement, and system design through teamwork and co-curricular programming, while demonstrate their knowledge and skills that are needed to be involved in a real project.

According to this, the professor SangHyung Ahn offered us the chance of developing a simulation program for the BAC whilst offering different solutions to their situation.

1.2   Motivation

Trying to increase the customer satisfaction of an airport seems an easy task since most of us are regular customers and we know what are we constantly complaining about. The difficulty arises when one really has to look into the problem and solve it.

As engineering master students, the curiosity to see the inner and actual functioning of an airport and more, if it is as important as Brisbane Airport.

The opportunity to work on a real project, knowing that the people who are going to evaluate the project are specialists in the field in which will be working makes the motivation and involvement much greater.

According to this, the writer wanted to go in deep in this knowledge and try to apply some of the programming skills and methodologies learned at the Technical University of Catalonia.

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1.3 Previous Knowledge

This thesis will be based on the knowledge acquired during a subject called Transportation while studying the Master's Degree in Industrial Engineering. As one of the most important goals will be reducing the waiting time at the queue, different types of lines will be considered in order to analyze the current situation.

A deep study to carry out the project successfully will be necessary to be done. It will consist in researching other aspects shown in previous studies about airports, the improvements made the last years as the automation of some processes or comparisons with other airports in the world.

Finally, the point of this project will be to use our basic knowledge with the new concepts that we will learn from the articles and previous studies in different airports about the check-in area.

2. INTRODUCTION

2.1. Situation

It is known that in the near future a majority of airlines and airports are planning to invest in self-service processes and improving the level of service offered to their clients.

In this thesis will be explained the case of the Brisbane domestic terminal as it is planning to be extended; building a new runaway would mean the possibility of more planes landing and taking off the airport, which is traduced to an increase in number of passengers.

It will be studied the impact in the terminal check-in facilities of the increasing number of passengers predicted for the next years and possible reorganizations in the space and implementation of automated systems.

2.2. Objectives

The BAC is currently planning to renovate the current check-in facilities to accommodate needs for a major redevelopment and expansion of the Domestic Terminal Building (DTB) and surrounds.

In the near future BAC will be responsible of all the actual check-in and security facilities of the terminal and is interested in studying how to manage the cooperation between the airlines to profit and optimize the space.

The project thus aims to:

- Study the current situation and analyse the data to improve the check-in and bag drop areas by observing customer throughput and exploring opportunities for automatic and self-processes minimizing the expenditure while maintaining or improving the quality service.
- Design a simulation model taking into account the increasing passengers and the intention of automatizing some processes. Different scenarios of the model will be designed with the aim of maintain the customer's satisfaction so waiting times in each of the areas and services will be studied in order to reduce them.
- Define the Key Performance Indicators to analyse the situation and compare the scenarios to find the best option to optimize the Virgin Australia and Common Use areas. The cooperation between different sections will be also considered relevant

to the future, which means the possibility to transfer passengers between the different areas in the actual facilities when one of them gets overcrowded bearing in mind that when the Qantas and Virgin Australia leases are finished, BAC will manage all the equipment and airlines.

- Propose and quantify improvements for the terminal based on the results obtained with the different scenarios.

2.3. Overall extent of the contribution

This thesis contributes to the body of knowledge in some ways:

- It provides a systematic review of the literature. Articles regarding the matter improving check-in area of airports have been classified and analysed in order to facilitate future investigations.

- It describes the arrival process by a structural analysis of the Domestic Terminal of the Brisbane Airport and the understanding of the check-in procedure to optimize its performance.

- It presents how a simulation of the check-in area can be useful to modify either its distribution in the space and the operational issues in order to improve the real facilities of the terminal.

2.4. Structure of the thesis

Section 3 presents information about the Brisbane Domestic terminal and the problem statement to be studied in the project.

In the section 4 the literature that has provided information for the development of the simulation model has been analysed. The review protocol and classification criteria have been illustrated in detail.

Section 5 gives details of methodology to analyse the data and how the simulation has been carried on.

Section 6 presents the results obtained with the simulation process and new proposals or solutions will be recommended to the airport.

Section 7 shows the project's budget.

Section 8 gives some ideas related to the environmental impact this work can cause.

At the end of the thesis there are some sections explaining the final conclusions of this study and presents possible futures steps that may be done related to the work. Also there are some acknowledgments and the bibliography consulted to extract information for the thesis.

3. CASE OF STUDY

3.1. System's description

Brisbane Airport Corporation (BAC), the operator of Brisbane Airport (BNE), is a private, non-listed Queensland company, helping employ thousands of Queenslanders and creating economic opportunities for the state and city of Brisbane equating to more than $4 billion annually. BNE is the largest airport in Australia by land size (2700 hectares) and the third largest airport in Australia by passenger numbers with more than 22 million passengers travelling through the airport in FY15. BAC acquired BNE from the Federal Government under a 50-year lease (with an option to renew for a further 49 years) for $1.4 billion in 1997. Since the acquisition, BAC has assumed ultimate responsibility for the operations of BNE including all airport infrastructure investment with no government funding. Operating 24 hours a day, seven days a week, BNE has two major terminals servicing 26 airlines flying to 67 destinations. Additionally, BNE is highly recognised for their customer service quality; it was rated as Australia's No. 1 airport for quality of service 10 years in a row in an Australian Competition & Consumer Commission's survey, and 3rd in the 2014 Skytrax World Airport Awards for Best Airport in Australia/Pacific, Best Airport in the World (20-30 million passengers) and Best Airport Staff in Australia/Pacific categories.

BAC is currently working in the biggest aviation project in Australia, consisting of the construction of a new runway with a $1.35 billion investment. It will be 3.3 km long, 60 m wide, located 2 km west of and parallel to the existing runway and will have 12km of taxiways. Lighting, navigational aids and landscaping will also take place in this project. Environmentally sound and award winning, the project will create 2,700 construction jobs and predicted to deliver a regional economic benefit of around $5 billion per year by 2035. A key fact is that the runway will allow the same level of capacity as Hong Kong and Singapore airports.

The project started in 2014, and some phases have been successfully completed.

The site preparation and dredging works, consisting in clearing the remainder of the site, sand extraction from Moreton Bay to pile it on the site and a four year ground settlement period to create a solid base for the runway.

Nowadays the base is ready and it is being carried out the construction of the pavements and airfield, including pushing off the excess sand surcharge, constructing pavements and commissioning or commencing operations.

The runway is predicted to be done by 2020, when complete will give Brisbane the best runway system in the country.

As the Brisbane Airport would be then the biggest in Australia, the flights are forecast to grow from 227,000 in 2014/15 to over 360,000 by 2035. The plans for the next years are to assume the majority of the incoming flights to Australia as first point of contact to the country. Then the passengers will be transferred from the international to the domestic terminal to get their connection flights to their final destination.

Also, it is known that in the near future a majority of airlines and airports are planning to invest in self-service processes since the usage of self-service bag drop is increasing globally. Two of three main check-in and security facilities at the Brisbane Airport Domestic Terminal are leased to two major airlines: Qantas and Virgin Australia. The third check-in and security facility belongs to smaller low cost airlines and is currently managed by the BAC. Qantas was one of the world's first adopters in the self-service processes, while Virgin Australia introduced it only as part of its new Perth Airport terminal in 2015. By the end of next year, the lease of these two airlines will belong to the BAC who will be in charge of reorganizing the existing facilities and make a new operating plan including all the areas and all the companies performing in the Brisbane Domestic Terminal.

The domestic terminal has three distinct areas serving Qantas and Qantaslink at the northern end of the building and Virgin Australia at the southern end of the building and other carriers such as Jetstar, Tiger Airways and JetGo are located in the central area of the terminal. There is also a small area of International Connections, where people coming from international flights and have been directed to the domestic terminal to continue their flight until their last stop. Some airlines such Tiger Airways, Alliance and Skytrain can be found there.

The building has a two-storey curved building with three complete satellite arms extending beyond the building providing additional passenger lounge and gate facilities for airlines.

Two of three main check-in and security facilities of the terminal are leased to Qantas and Virgin Australia. The Qantas check-in facilities mainly consist of 43 automated check-in kiosks and 14 auto bag drop kiosks. On the other hand, the main check-in area of Virgin Australia provides only 16 automated check-in kiosks, 8 traditional check-in counters with a unique serpentine queue and 3 business check-in counters with 3 single linear queues and 8 manual bag drop counters that also have a unique serpentine queue for all the service points.

The common user area managed by BAC has 20 self-service check-in kiosks and 8 automated bag drops, with singles queues for each of the services

The two main areas that will be studied are detailed in Figure 1 corresponding to Common User and Virgin Australia. Qantas will be out of the scope of this project.
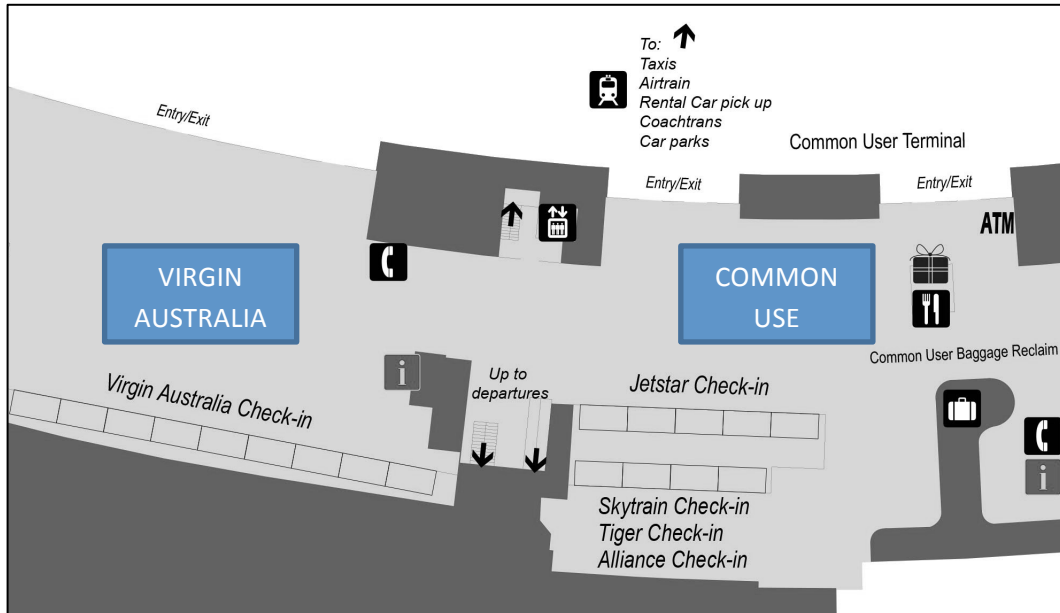
Figure 1. Areas at the terminal of Virgin Australia and Common User.

3.2. Problem Statement

The anticipated increase of demand in the next five years in the current facilities of the terminal leads to the study of space optimization in order to reduce the waiting time of the passengers while maintaining the quality of the service.

The level of service at the airport is a common topic studied during years and it is seen that users are becoming more demanding, specially those who travel frequently.

The main problem lies in the check-in and security control zones that tend to be the ones more overcrowded particularly at peak hours. For that reason, the scope of the project will include the check-in areas as being the first contact of the passengers when entering the airport.

As explained before, BAC is interested in automating some of the facilities.

The Virgin Australia Area is the only one having a huge amount of traditional check -in

counters as their intention is to keep the physical contact with the client. With that in mind, it will be studied the possibility of replacing the counters for self-service check-in kiosks. In this case, there will be more passengers going through the bagdrop as before they were leaving their luggage in the belt of the counter desk. As the number of passengers will increase, new service stations for bagdrop will be opened but taking into account the opening cost.

The existance of two different areas of study gives the opportunity to redirect people from the service point in there area to the other, in case the first one is very crowded containing a more than a certain amount of people in the queue. The proper management between the areas will be another improvement to consider in order not to increase passengers waiting times.

Another possible change in the current facilities would be the type of queue, linear or serpentine.

Bearing in mind the practical variations in the present check-in facilities that have been exposed below, different scenarios will be analyzed in order to compare the results and extract conclusions to be able to give recommendations to the airport.

In each of the scenarios discussed, there may be several situations with an increase of demand in the number of passengers arriving to the Common Use or Virgin Australia areas. These situations will be explained in more detail in the next section.

A determined number of Key Performance Indicators (KPIs) have been considered and will be analyzed and compared in order to assess the validity of the situations and scenarios.

The study of the results and conclusions extracted from the KPI will lead to recommend improvements in the check-facilities.

BAC will use the project recommendations to guide renovation decisions for the domestic terminals for Virgin Australia and other smaller airlines. In conclusion, they seek to maintain their high customer service rating and possibly find areas to cut costs by implementing a new layout and queuing system for actual use in the domestic terminal. All project recommendations are to align with Brisbane Airport Corporation (BAC) plans for renovating current BNE domestic check-in facilities to accommodate needs for a major redevelopment and expansion of the Domestic Terminal Building (DTB) and surrounds. This project will aid BAC's vision for BNE to be the preferred choice of passengers, airlines, business and the community.

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4. LITERATURE REVIEW

4.1. Classification Criteria

One of the most important parts of a scientific thesis is the analysis of the literature. Knowing where to look up for the right information, organising and examining it are key steps to perform a strong-based thesis. Therefore, a considerably amount of time has been spent in this part of the project.

The quantitative tools to support the analysis of the data collected from the airport to develop a simulation model constitute the main literary reference to this thesis.

A lot of research and studies related to the improving check-in facilities of the airport have been carried out along the years and are presented below. It would be useful to place our work and select the different techniques for developing a simulation model and consequently define a new configuration for the terminal.

4.2. Literature Analysis

Having a good customer service has been the main objective of almost every airport from a long time ago.

Hon Wai Chun and Raymond Wai Tak Mak created a knowledge-based simulation system to predict check-in counter resource requirements in an international airport. An intelligent resource simulation system was used to calculate the number of check-in counters needed to provide a good quality service to customers. [9]

In 2001, Paul E. Joustra and Nico M. Van Dijk demonstrated that simulation is necessary to evaluate check-in by discussing why queuing theory results are too limited but useful to predict queuing times for check-in counters at airports. They analysed two studies at the Airport of Amsterdam, the first study improves the personnel planning of the check-in counters and the second has been conducted to determine the maximum possible growth of Schiphol with respect to check-in facilities. [16]

In terms of the level of service (LOS) at the airport, Anderson Correia and S. C. Wirasinghe evaluated different methods of LOS and recognized that the capacity of any given airport facility cannot be evaluated without defining acceptable LOS values. This study has seen that there is no procedure for LOS evaluation at airports because of its dependence of many quantitative and qualitative variables. [18]

Based on the work of Nico M. van Dijk and Erik van der Sluis in 2005 deepen the check-in problem by proposing a combination of simulation and integer programming (IP) that can be regarded as a new optimization tool. Their main objective was the customer satisfaction and the cost effectiveness, [14]

Same year, Ervina Ahyudanaril and Upali Vandebona proposed a model based on queuing theory concepts and attempts to compute the optimum number of check-in counters based on cost minimization. The main two problems were the lack of consistent data and the difficulty to find the arrival distributions. [3]

Later on, using the model of Van Dijk, Doina Olaru and Stephen Emery have developed a more extensive simulation an optimization for modeling the operation of airport passenger terminals. This model can evaluate the efficiency of the entire complex of operations in the terminal. Triangular distributions have been used for the check-in time depending on the purpose of the trip. [15]

Giuseppe Bruno and Andrea Genovese, in 2010, focused on the mathematical model for the optimization of the check-in service problem, proposed new models for the problem comparing them with some well-known combinatorial optimization and showing the complexity of the models. [17]

Kristina Marintseva made a comparative analysis of check-in technologies at the airport. The M/M/s modeling has been used for calculating the suitable characteristics of the check-in area by simulating every technology. The waiting time has been reduced almost one hour thanks to the introduction of a dynamic approach to the opening and closing of check-in counters. [11]

After that, Andreas Wittmer in 2011 made a research about the acceptance of the self-service check-in at Zurich Airport. Even if the traditional check-in counters remain important for different travellers, for people with high travel frequency is more comfortable to use e-check-in methods. It has been detected that the satisfaction of the customers is related to the waiting time and the e-check-in methods can help reduce waiting time if adequate luggage drop facilities and processes are in the right place. [17]

M. Nandhini and Palanivel Kuppusamy have studied different factors such as the time of the day, day of the week, destination or number of passengers per flight in order to decide the optimal number of check-in counters to open for departing flights. After a mathematical model that represented the airport check-in process, making some hypothesis and adding

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some constraints, they have proposed to use a dynamic opening and closing of counters in order to reduce the number of counter operators during the last hour of check-in. [19]

Thanks to previous studies, Ahmad Thanyan Al-Sultan had been able to develop a developed a check-in allocation for airport terminal which decomposed to several check-in zones which have different counters capacity. A combination of mathematical programming and simulation has been made in order to study queuing theories. [13]

In the same line of work, Miguel Antonio Mujica Mota and Catya Zuniga have presented an algorithm that satisfies different mandatory restrictions and with the simulation is obtained the best configuration to maintain the quality indicators at the desired level. After their first study, they have evolved their model so it can be used in a wide range of problems to generate more robust solutions [6] & [7]

In 2014, Yedi Yang and Jin Li studied about the passenger flow simulation with Anylogic based on a subway station. Their study was focused on the impact on some parameters on the average queuing number by opening and closing the number of entrance ticket windows. [20]

In order to do an accurate pedestrian modeling, the interaction among pedestrians and the built environment have great relevance while trying to simulate the real world. Wenbo Ma and P. K. D. V. Yarlagadda examined different manners to make the more realistic heuristic approach of the dynamics of pedestrians. [21]

Finally, Gerson E. Araujo and Hugo M. Repolho from Brazil developed a new methodology to optimize the Airport Check-in allocation problem combining optimization, simulation and adjacent resource scheduling. The objective was to determine the optimal number, location and schedule of check-in desks. [1]

As it is seen, most of the articles demonstrate that the simulation is a very useful tool to understand the performance of the real situation. However, using optimization and simulation seems to be the best idea to see and minimize the current problems in the domestic terminal of the Brisbane Airport.

Also, as it is known that the airport wants to automate the check-in area of the terminal and that the people with high travel frequency is more comfortable to use e-check-in methods, the methodology that some of the articles use to calculate the minimum number of check-in counters will be useful to minimize costs and to provide a good quality to the customers.

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The dynamic approach to opening and closing of the check-in counters will be considered when implementing improvements in order to minimize the waiting time at the queue.

All these articles based their algorithms in the Level of Service (LOS) indicators so they can measure the satisfaction of the customers and some characteristics associated with the comfort inside the terminal such as available area per passenger or the speed at which the passenger can travel inside the terminal. The parameters that are considered necessary to evaluate the level of service are the average waiting time, maximum waiting time and the percentage of utilization of one service. These will be some of the simulation results of this project.

In the other side, as it has to be considered the interaction among pedestrians and building facilities, it is out of our boundaries to include different characteristics to the passengers and in the model.

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5. DATA ANALYSIS AND SIMULATION

5.1. Data Collection

Collecting quantitative data for the real system of the Brisbane airport is the first step to build the model in order to carry out an optimization and simulation process.

Videos recording passengers in the domestic terminal have been provided by a previous project done by UQ students about the level of service and client satisfaction in the Brisbane Airport. Six cameras where placed in strategic positions of the terminal in order to capture all the areas from various angles and perspectives and be able to analyse the videos in the future for many purposes. The time slots selected for the recording were those where the terminal tends to be more crowded, considering Mondays early morning (5 to 7 am) or Friday in the afternoon (5 to 7 pm).

As well as it has been explained in the section 2, there are two different areas that will be treated differently in the Data Collection. On one side, there is the CU area where Jetstar, Tiger Airways and JetGo airlines operate, and on the other side there's only the Virgin Australia Airline.

It has to be mentioned that two types of limitations were found in this step of the project. Some are due to the structure of the building (columns obstructing visibility and blind spots in some of the areas) and others to the recording devices (finite battery of the cameras or possible errors during recording).

From this, data has been collected from camera footage of the two main areas mentioned before (CU & VA). Data inputs are limited to customer check-in for domestic flights exclusively. It has been noted:

- The time recorded when people arrive to the queue of the facility.

- The time recorded when passengers arrive to the check-in facility (desk or kiosk) or bag drop belt and are about to start to use the service.

- The time recorded when customers leave the equipment.

These times were referred to each of the following stations:

1. Automated kiosks (CU & VA)

2. Semi-automated bag drop (CU)

3. Manual check-in & bag drop (VA)

4. Business manual check-in (VA)

In reference to the times recorded, a number of simplifications have been made during the collection data:

- A group of people has been treated as only one person, but the number of people has been counted in order to know the average time of one person.
- If one passenger goes first to one service point but doesn't work and then starts in another, it has been counted only the second service time and the waiting time has been defined since the passenger arrives until he/she starts in the second service point.
- If one passenger is on one line and decides to change line, the time arriving at the queue is the time when that person arrived to the first queue.
- If someone starts doing the queue but leaves before arriving to the service point, this waiting time is not counted.
- The TBA has been calculated by subtracting the time of arrival of one passenger to the queue and the next one.
- The ST has been calculated between the time recorded when the passenger arrives to the facility to start using the service and the time when leaving the equipment.

The model was employed to test passenger throughput of various configurations of automated kiosks and bag drops. In the next steps will be explained how the program works and the different scenarios built in order to achieve the objectives of the project.

5.2. Why Simulation Modeling

Modeling is a way real-world problems can be solved as a model can be built using a modeling language to represent the real system. The model is always less complex than the original system as there are only included the most relevant details.

Simulation is normally used when conducting experiments on a real system would suppose high costs because of the prototyping and testing or because the duration of the experiment in real time is impractical. When using a simulation program, there's a risk-free environment that will help to make the right decision before making real-world changes.

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Once the model has been built, is it possible to explore and understand the system's structure and behaviour, test its functions under a variety of conditions, compare different scenarios and optimize. In this way, it permits to save money and time as well as an increased accuracy thanks to the visualization in 2D or 3D that allow concepts and ideas to be easily verified.

In comparison to a mathematical model, the simulation model is also based in algorithms and mathematical expressions. In the mathematical model the constraints included may not be possible in the real situation while in the simulation modeling the conditions can be adjusted after seeing the 3D model so it will be guaranteed that the solution is reliable.

Finally, the ability to play and animate the system behaviour in time is one of its great advantages as it would be useful for demonstrations, verification and debugging.

In the first steps of the project, the intention was to build and excel model (mathematical) and a simulation model in order to compare the results between them. The problem was the complexity of the model, it was possible to build a very simple excel model but it did not accept the distributions from the data. In consequence, the inputs of both models will have been different and it would have been difficult to compare the results. Simulation has been thought to be the best option.

Simulation modeling has been very common in all type of industries (from low to high abstraction level): supply chain, transportation, passenger terminals, manufacturing, healthcare, marketing, warehouses operations…

In the Figure 2 there are shown three methods that serve a specific range of abstraction levels: System dynamics, Discrete Event Modeling, Agent based Modeling.
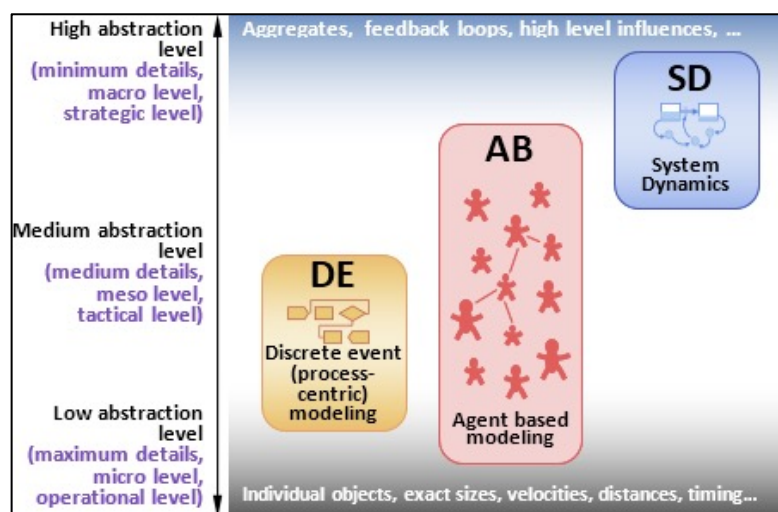
Figure 2. Methods in Simulation Modeling.

In this project will be used the Agent Based Modeling because of its wide application in all abstraction levels.

5.2.1 Anylogic Model

The simulation would be carried out using a program called Anylogic where the CU and VA of domestic terminal of the Brisbane airport will be represented with 3D characters. Anylogic is a tool that includes all the most common simulation methods nowadays.

One of the problems presented at the beginning of the project was the difficulty of the technology to be used: Anylogic. This is a new technology, a program with much potential but much to discover.

There are three different standard libraries in Anylogic: Process library, Pedestrian library and Railway terminal library. In this project, Pedestrian Library is the best option because it simulates pedestrian flows in "physical" environments by allowing you to create models of buildings and areas with large numbers of pedestrians such as subway stations, security checkpoints and streets.

5.2.1.1 Main Parameters

Simulation modeling requires special software tools that use simulation-specific languages. The first step is to create a model that corresponds to the structure of the Brisbane terminal, it is necessary the floor map of the area and the basic elements that will help in the configuration of the terminal.

The facilities in the two areas of study are represented in the Figure 3 and consists of the floor map provided by the airport and the correspondent elements in 3D that have been placed in the *Anylogic* program. The different parts shown are:

Virgin Australia area:

1. Check-in kiosks
2. Manual check-in counters
3. Business check-in counters
4. Bag drop counters

Common User area:

5. Check-in kiosks
6. Automatic bag drop

Figure 3. Floor map of the terminal with the 3D elements of each service.

The basic elements that can be found in the program are:

*   Walls: Area that the pedestrian cannot cross in the simulation modeling.

*   Pathway: is used to restrain pedestrian movement with a walking corridor. When moving along the pathway, pedestrians try to keep within the pathway bounds.

*   Services: are the objects – such as turnstiles, cash desks, ticket windows, and ticket machines – where is possible to receive pedestrians. Is possible to introduce only one serpentine line for all the services or one line for each of the services points depending on the interest. There are two different options:

    o   Linear: like a turnstile, pedestrians continually move from the line's starting point to the line's ending point.

    o   Point: like a ticket window, the pedestrian services occur at a specific point where pedestrians wait for the given delay time.

The *walls* have been used as delimitation for the passengers to not cross some areas where there's a bar or a shop in the real terminal. The *pathway* has been used as a corridor in order to show the passengers what is the way that they have to follow

after the services to go to the next one. The services, in this case, are all services *points* because pedestrians need to stop at a certain point of the services to be served.

In the services case, when there is one line for each service point, there are given in the program three different options: *Closest queue, Shortest queue or choosing individually for each pedestrian the queue where they should go.*

The option that best fits with the performance of the terminal is *Shortest queue* where the passenger chooses the queue where there are fewer passengers. Even so, it has been detected during the simulations that there is a random factor that sometimes makes the pedestrians to use the shortest line between the closest ones. However, *Anylogic* has detected this error and is working on it for the following versions.

ORIGIN/ DESTINATION	COMMON USE			VIRGIN AUSTRALIA			
	Kiosk	Bag drop	Security point	Manual Check-in	Kiosk	Bag drop	Security point
Entrance	90%	10%	-	60,8%	29,2%	10,0%	-
Kiosk	-	83,5%	16,5%	-	-	93,9%	6,1%
Bag drop	-	-	100%	-	-	-	100%
Manual Check-in	-	-	-	-	-	-	100%

Table 2. Percentage of people that go from one service to another.

Then, it is necessary to include a flowchart to define the processes that take place in the pedestrian dynamics models. In the table below, it is shown the percentage of people that goes to each of the services and it has been calculated thanks to the data collected.

As it is seen in the table 1, the 90% of the people of CU go to the kiosk but there is a 10% that goes directly to the bag drop because it will print the boarding pass. This is possible thanks to the opportunity to check-in online previously. After the kiosk, if they have suitcases to check-in, passengers will go to the automatic bag drop in order to leave them. Most part of the customers, an 83,5%, need to check-in their luggage before going to the security point. The remaining 16,5% will go directly to the security point.

In the case of the VA, Virgin Australia area, there are three different options when the passengers arrive. It has been seen that the 60,8% believe in the rapidity of the manual check-in. The 29,2% go to the kiosk and only a 10% have checked-in online before and only need to print their boarding pass while leaving their suitcases in bag drop services.

Finally, is has been demonstrated that a 93,4% of the people go to to the bag drop after the kiosk to drop off luggage.

In the flowchart to be designed in the program is important to know the different blocks than can be put and the number of inputs and outputs that each of them have.

- Ped Source: Generates pedestrians. Is usually used as a starting point of the pedestrian flow.
- Ped Go To: Causes pedestrians to go to the specified location that can be defined by a target line, area or a point. The pedestrian has to reach a given point, or any point of the specified line, or area.
- Ped Service: Simulates how pedestrians are serviced in the services.
- Ped Wait: Causes pedestrians to go to the specified location and wait there for a specified period of time.
- Ped Select Output: Block with one input and maximum five outputs. There are two possibilities for the outputs: conditions or probabilities.
- Ped Sink: Disposes incoming pedestrians. Is usually used as an end point of the pedestrian flow.

Referring to the blocks explained, it has been used one Ped Source for each one of the entrances of the CU and VA areas, one Ped Service for each of the Services and one Ped Go To every time a passenger needs to move from one service to another. There are no Ped Waiting blocks because the correct use of them are for the waiting areas before going to gates but in this case it is out of scope. The Ped Select Output has been used after each of the services when the passengers have to go from one service to another as it is shown in Table 1. Finally, each of the Ped Sources requires a Ped Sink as the ending point of the path.

Before doing the simulation, different seeds have been fixed for each of the distributions. Then, as the system is designed in a way that against the randomness responds in a similar way, it has been simulated with aleatory seeds in all cases. The fact of introducing different seeds in all simulations should not affect to the comparison of the results thanks to the robust system that has been created.

In the Figure 4 it is shown a flowchart with the possible paths of the passengers as it has been explained in this section.

ETSEIB
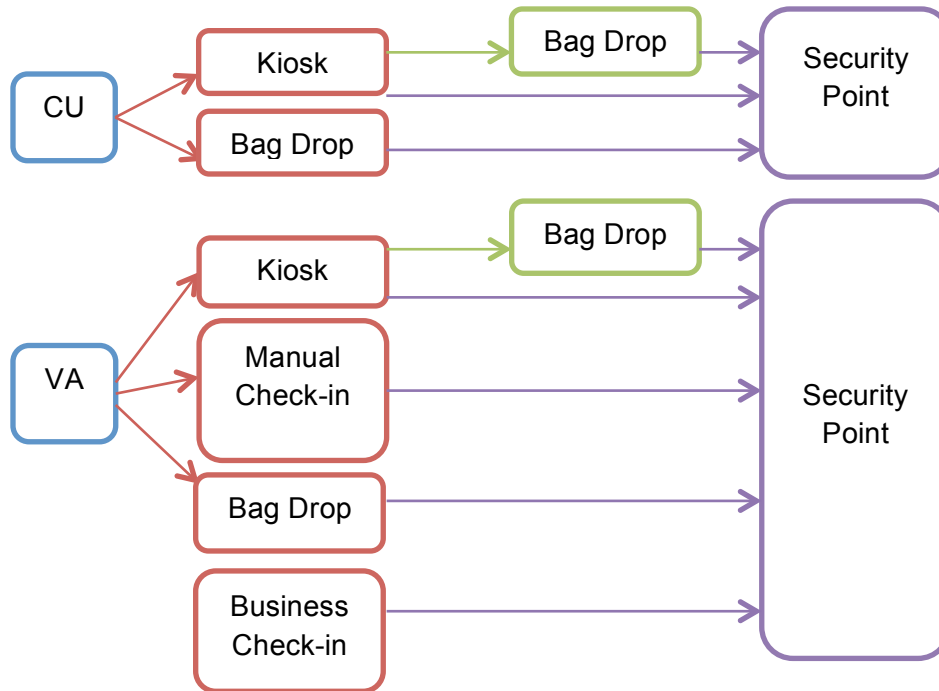
Figure 4. Paths followed by passengers in the different areas.

After that, is necessary to link the flow chart with each of the 3D objects and include some parameters in the model: time between arrivals from passengers to each type of check-in or bag drop and the service time at each part of the facilities. Those times, as it has been said, have been extracted from the data collected from the videos.

The program *Anylogic* requires introducing the times according to their behaviour. For that reason, they have been analysed using a statistic tool called *@Risk* to see which distribution they were following. The distribution and their respective parameters will be inserted in the simulation program.

5.2.1.2 Fitting distributions

The data for fitting a distribution corresponds to the Time Between Arrival (TBA) of the passengers to the queue of the different facilities in the airport and the Service Time (ST) when they are using the system their selves or attended by an airport worker.

TBA and ST have been extracted from the data collected from the recordings.

The mentioned times for the different areas in the domestic terminal are:

In the Common Use Area:

- TBA and ST to the check-in self-service kiosks.
- TBA and ST to the automatic bag drop belt.

In the Virgin Area:

- TBA and ST to the check-in self-service kiosks.
- TBA and ST to the bag drop counter.
- TBA and ST to the manual check-in attended by an airport officer.
- TBA and ST to the business manual check-in attended by an airport officer.

There are a variety of programs that, by entering the data, are able to calculate the parameters according to the chosen distribution and then choose the most appropriate distribution. In this project, the possibility of doing this task has been studied with the program *Minitab*, which had been previously used in the university (UPC). The problem of this program was that the only version available was Minitab Express and was not enough powerful for this.

Then, a new tool was proposed, called *Statistica*. It was able to provide all what needed but it required a very special treatment of the data and was not able to analyse such a large number of data.

Finally, *@Risk* has been used to analyse risk and uncertainty in a wide variety of industries, from the financial to the scientific, and has been used to perform risk analysis using simulation to show multiple possible outcomes in a spread sheet model, and how likely they are to occur.

The program *@Risk* permits to define distributions using historical data. Firstly, is necessary to plot an histogram of the data in order to have an idea of what distribution could follow each of the times mentioned before.

Then, it mathematically and objectively computes and tracks many different possibilities and shows the probabilities and risks associated with each one. In that way, it is possible to judge which risks to take and which ones to avoid, allowing for the best decision making under uncertainty.

For each of the TBA and ST, the program ranks by different criteria the different possible distributions in which that data better fits. The criteria to sort the distributions are:

- Name
- Akaike Information Criterion (AIC)
- Bayesian Information Criterion (BIC)
- Chi-Squared Statistics
- Kolmogorov-Smirnov Statistic
- Anderson-Darling Statistic

The criteria considered more relevant to select the best distribution for each data set, have been the AIC, BIC and Chi-Squared Statistics.

The **AIC** is a measure of the relative quality of statistical models for a given set of data, estimating the quality of each model, relative to each of the other models. Is important to bear in mind that it can tell nothing about the quality of the model in an absolute sense. If all the candidate models fit poorly, AIC will not give any warning of that.

The **BIC** is a criterion for model selection among a finite set of models where the model with lowest BIC is preferred. It is based, in part, on the likelihood function and it is closely related to the AIC. When fitting models, it is possible to increase the likelihood by adding parameters, but doing so may result in over fitting. Both BIC and AIC attempt to resolve this problem by introducing a penalty term for the number of parameters in the model; the penalty term is larger in BIC than in AIC.

The **Chi-Squared Statistics** is any statistical hypothesis test wherein the sampling distribution of the test statistic is Chi- Squared distribution when the null hypothesis is true. The chi-squared test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies in one or more categories.

Based in the standards, it has been proved that the three mentioned select the same preferred distributions for each case. For that reason, the one finally chosen has been the AIC. The distribution plots can be seen in the Appendix A.

Once the @Risk analysis has been finalised, it is possible to conclude that in all cases the TBA and ST obey the listed distributions with its corresponding parameters.

Exponential (λ)

Gamma (α, β)

Lognormal (μ, σ)

In the table below, the distribution in which data set fit sets are shown, as well as its parameters.

		TBA	ST
CU	**Check-in kiosks**	Exponential (163.97)	Lognormal (4.007, 0.70238)
	Bag Drop	Exponential (132.43)	Lognormal (4.2270, 0.86792)
VA	**Check-in kiosks**	Gamma (2.4882, 72.208)	Gamma (3.7266, 31.554)
	Bag Drop	Exponential (146.04)	Lognormal (3.9410, 0.82765)
	Manual check-in	Exponential (197.89)	Lognormal (4.6076, 0.8447)
	Business check-in	Exponential (127.55)	Lognormal (3.9335, 0.70889)

Table 2. Distributions and parameters for all the services.

As seen in Table 2, almost all services follow an *Exponential* distribution for the Time Between Arrivals except the Check-in Kiosk in VA that follows a *Gamma*. Knowing that the data was extracted in the critical hours when the difference between arrivals of one passenger to the next one is very small and makes sense to follow an *Exponential* distribution.

In relation to the *Lognormal* distribution that follows the service time, it is considered completely valid since most of the passengers take an approximate time similar to the calculated average time and a smaller proportion of passengers are served in times lower or greater than the average.

In the Appendix at the section 1 can be found some plots from @Risk representing the relation between the data collected and the distribution that best fits with it.

5.3. Definition of the scenarios

In order to make a correct definition of the scenarios, it must be first clarified the limitations that to deal with due to the indications of the BAC.

These scenarios have been defined based on the space currently available, so the different scenarios include changes that refer to the actual configuration of the terminal.

As mentioned in the introduction, there are two different ways of implanting these changes.

One is based in the type of line of the queue of the services. As some of the articles in the

literature review have noted, having only serpentine line seems to be more effective than one line for each of the services points.

The other one is based in the interest of the airport to automate the Virgin Australia area. In this case there will be changed the manual check-in services into automatic kiosks, but treated as a different area because the serpentine line will remain as it was for the manual check-in points. As it is supposed, as the people of the new kiosks have the possibility to go to the bag drop, more services points in the bag drop of VA will need to be added.

Furthermore, it has been studied the capacity utilization of the VA services and has been calculated the percentage of time that the services are in use in reference to the whole time that they are available. In the next table are shown the results:

	Capacity utilization
Check-In Kiosks (16 kiosks)	21 %
Manual Check-In Counters	85 %
Bag Drop	43 %

Table 3. Capacity Utilization of VA services.

This study has been carried out in order to analyse these percentages and, as it is seen, the kiosks of VA are under utilization being very small compared to the manual check-in. The conclusion is that the 60% of the people prefers going to the manual check-in instead of the kiosks and the main objective of this scenario will be to equilibrate those percentages of usage. The main scenarios that have been thought to be interesting to analyse are the following six:

- Scenario 1: Base case, where it is represented the current situation.
- Scenario 2: Changing the type of queue in the bag drop of CU.

Figure 5. Serpentine line in the CU bag drop

- Scenario 3 & 4: Changing the manual service into 6 kiosks with a serpentine line or one line for each kiosk and installing one new bag drop in the VA area.

Figure 6. Automatic check-in kiosks instead of manual counters in VA.

- Scenarios 5 & 6: Changing the manual service into 6 kiosks with a serpentine line or one line for each kiosk and installing two new bag drops in the VA area.

In order to decide the final scenarios, a previous study has been carried out focusing on the scenarios from 3 to 6 in order to decide which is the best option.

First, is has been calculated the optimal number of kiosks needed to serve the same number of passengers without increasing the waiting time. Simulations have been done with varying the number of kiosks between 4 to 7. The results obtained show that placing 4 or 5 kiosks would not be enough to serve the same amount of passengers than the previous system. Finally, it was concluded that six kiosks were sufficient in order to minimize the cost of opening. So the scenarios 3,4, 5 & 6 will have 6 automatic kiosks instead of the manual check-in. The final decision will be explained in Section 6.

Adding this number of kiosks permits an increase to 60% of utilization of the kiosk and an increase to 86% in the bag drop, in reference to table 3.

By having a greater number of kiosks, the number of people that will be directed later to the bag drop is increased and, for that reason, it has been studied to increase in one or two the number of open bag drops.

In addition, the fact of having enough space in the manual check-in area permits us to differentiate the new kiosk area in order to observe if maintaining the serpentine of the manual will get better results.

Each of these scenarios counts with 12 different situations to compare the results between of them. It has been explained that in the next years the BAC expect to assume the majority of the incoming flights to Australia as first point of contact to the country and then the passengers will be transferred from the international to the domestic terminal to get their connection flights to their final destination. It is important to notice that after fixing all the parameters needed for the scenarios, is necessary to choose the methodology of simulation.

According to this, only one of the current areas (CU & VA) can have an increase of passengers so it has been studied the possibility of receiving a 20% or a 30% in one of the areas.

When having a 20% or a 30% in some area, there is always a bottleneck in one of the areas that can have some consequences in the level of service and a facility in the contrary area would have extra capacity for passengers. This is the reason why some of the studied situations are based in the redirection of customers to the less travelled areas.

In the case of VA, when the number of arriving passengers is increased, it has been observed that the manual check-in gets very crowded and, instead, the kiosks are underutilisation. Therefore, the most feasible option has been sending passengers from the manual check-in to the kiosks when the capacity of the line is not enough to serve the number of passengers waiting at that moment. In this way, 25 passengers will be the maximum number of people that will wait in the queue. Otherwise, it will be offered to use the kiosk instead and thus reduce their waiting time. There is a margin of error in the program of the people waiting at the serpentine queue around 2 or 3 people. That is because when the program realises that there are 25 persons in queue and starts sending persons to the other area, there might be some passengers already going to manual check-in queue and so, they are not counted, as they have not arrived yet.

In the case of CU, when increasing number of passengers in a 20% or 30%, it has been observed that in the bag drop there is not enough space for that amount of people. Knowing that there is a margin of error of 2 or 3 persons, it has been fixed a maximum number of 18 passengers in the bag drop of CU. Then, taking into account that in the bag drop of VA there is enough capacity to serve more passengers, it has been decided to recommend and

redirect passengers from the bag drop of CU to the bag drop of the VA. In this way, they will perform the same operation in a shorter time and maintaining level of service to passengers.

In order to be able to compare the scenarios and decide which are the best improvements in each situation that the BAC can face in the coming years, have been measured four different Key Performance Indicators that were mentioned before and will be explained hereunder.

As the waiting time is one of the most important factors to take into account when assessing the level of service, three of the four KPI's are related to this.

One is the average waiting time in the queue, another is the maximum waiting time and finally is considered that having a high percentage of passengers waiting less than x minutes (x depending on the type of service and the type of queue) creates a positive impact on the opinions of the clients. The last KPI that has been considered relevant to compare the scenarios has been the maximum number of passengers in the queue since it is believed that reducing that number will help in reducing the waiting times and will increase customer satisfaction.

Once the results have been validated, the next step is to analyse the statistics collected and provided by the model. After several simulations of each of the scenarios will be possible to determine an optimal scenario for the renovations expected. In this project, 30 simulations have been made for each of the scenarios and situations. The mean of these simulations have been calculated in order to obtain the final results will be explained in the next section.

6.   RESULTS AND RECCOMENDATIONS

6.1. Results from the simulations

Once having the scenarios defined as explained in section 5 with the different situations of demand, number of services working, type of queue or redirection between areas, the simulations have been carried out.

Each of the results considered interesting to obtain in each of the simulations has been recorded in a txt file. From that, it has been necessary to analyse, assemble and sort all of them in an Excel file, to be able to proceed with the study.

It has been considered suitable to represent the final results in a table. The rows represent the different scenarios tested, each of them has different configuration in space of the services or queues. The columns correspond to the distinct situations that can occur in each of the scenarios. This circumstances are referred to the possible increase of passengers in some of the areas because the increasing number of flights in some airlines in the next years or the fact of redirecting clients between areas to reduce overcrowding.

For each of the scenarios and situations that have been simulated, is has been considered relevant for further analyse to register the results explained below.

Table I:

- Average waiting time at the queue of each passenger at each facility.

- Maximum waiting time a passenger is waiting at the queue of a particular service.

Table II:

- Maximum number of people waiting in the queue. Note in this case that the services that have a linear line for each service, the sum of all the persons in the different queues is what has been counted to be able to compare this number with the cases where there is a unique serpentine queue for all the service points.

- It has been considered interesting to evaluate the customer satisfaction to reflect the percentage of passengers waiting less than X minutes in the queue. The number of minutes depend on each of the services as some of them are usually more crowded than others, so that is the reason of not having considered the same number to all of

them. The amount of minutes thought to be acceptable after seeing the results obtained simulating have been:

In Virgin Australia area:

- o Business check-in: 3 minutes. This section usually does not get to large queues but people are paying more for the service so they require having special attention and fast assistance.

- o Manual check-in: 8 minutes. That is one of the facilities that usually have more people at the queue.

- o Bag drop counters: 5 minutes.

- o Check-in kiosks: 1 minute. It is the fastest service and people do not tend to wait at the kiosks as there are great amount of them and there are also a lot of passengers preferring to use the manual check-in.

In Common User are:

- o Check-in kiosks: 1 minute. These kiosks also give a fast service so there are no queues.

- o Bag drop belts: 5 minutes.

- In the situations where people are sent from the CU area to the VA or vice versa, it has been calculated the percentage of persons that have been redirected out of the total using the queue the queue to what they where going in the first place but exceeded the maximum number of passengers.

The final tables I and II that contain the results mentioned are shown below as tables 5 and 6 including all the scenarios with its different situations collecting the results of the simulations. As it has been explained, in some of the scenarios there are situations that are not possible so are the ones shaded in the tables.

Scenario	Changes in configuration/Increasing volume of Passengers		Base case - Current situation		Increasing 20% Demand VA		Increasing 30% Demand VA		Base Case sending passengers from manual to kiosks		Increasing 20% demand in VA sending passengers from manual to kiosks		Increasing 30% demand in VA sending passengers from manual to kiosks		Increasing 20% Demand CU		Increasing 30% Demand CU		Base Case sending passengers from bag drop CU to VA		Increasing 20% demand CU sending passengers from bag drop CU to VA		Increasi demand C passengers drop C
			Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
Scenario 1	Base Case (6 Manuals & 6 Bag Drops)	Business VA	30,782	631,253	41,339	677,759	43,456	723,773	27,634	393,32	42,3	645,594	45,481	802,583	28,2358	779,591	29,459	465,083	30,782	631,253	30,86	389,408	31,518
		Manual VA	317,515	1086,3	422,955	1444,5	584,09	1792,5	290,058	1005,6	372,501	1042,8	430,405	1046,7	240,391	1034,7	250,183	897,9	317,515	1086,3	238,258	1107	243,159
		Bag Drop VA	78,5269	215,5	80,0661	224,7	84,2984	281,7	80,9244	267,3	90,5814	362,7	126,958	741,9	71,8794	148,8	80,321	244,2	78,5269	224,7	92,9432	518,1	108,264
		Kiosk VA	0	0	0	0	0	0	0	0	0,00095	2,98039	0,07876	49,2849	0	0	0	0	0	0	0	0	0
		Kiosk CU	0,54684	239,171	0,59513	250,086	0,40137	229,675	0,35866	139,443	0,43894	270,322	0,57887	202,672	1,1858	245,364	1,5603	249,061	0,54684	245,364	1,513	215,619	1,9034
		Bag Drop CU	91,062	1849,6	92,578	1972,5	101,475	2092,2	89,649	899,4	103,087	2117,1	98,874	2513,7	171,556	1877,4	288,545	2090,1	91,062	2090,1	151,59	1615,2	189,09
Scenario 2	Change to Serpentine Line in Bag Drop CU	Business VA	32,038	760,073	32,946	815,873	50,698	833,117	29,147	390,656	40,731	612,313	46,26	671,46	29,671	521,347	30,632	699,505	28,1435	404,713	28,324	549,505	28,507
		Manual VA	233,351	936,3	417,818	1601,1	560,68	1679,4	258,346	901,8	385,643	1078,5	423,572	1076,7	260,225	1018,2	257,714	871,5	248,468	1322,4	246,395	1258,2	268,954
		Bag Drop VA	80,4829	229,5	81,3486	251,4	88,9265	308,1	82,1207	269,1	90,9012	295,8	125,144	675,6	80,7529	273,3	81,4491	265,2	81,5717	284,7	109,533	406,8	151,552
		Kiosk VA	0	0	0	0	0	0	0	0	0	0	0,0638	37,1956	0	0	0	0	0	0	0	0	0
		Kiosk CU	0,39438	172,83	0,42503	219,89	0,53551	137,772	0,42404	220,49	0,77073	188,067	0,38393	125,813	1,0708	407,613	1,5624	591,751	0,57613	205,27	1,05271	245,509	1,8959
		Bag Drop CU	153,057	588	144,921	660	165,306	739,8	138,107	559,8	157,086	619,8	145,792	565,2	240,928	729,3	325,698	790,8	125,117	442,2	200,983	524,1	218,972
Scenario 3	Change Manual VA to 6 Kiosks with one serpentine line and 7 Bag Drops	Business VA	30,147	454,045	38,965	474,61	43,163	536,129															
		Manual VA	111,511	629,4	262,761	1155	305,268	1262,4															
		Bag Drop VA	242,923	809,4	310,418	949,8	369,416	1083,6															
		Kiosk VA	0	0	0	0	0	0															
		Kiosk CU	0,51236	201,618	0,76068	318,575	0,6879	324,048															
		Bag Drop CU	91,044	2109,9	102,731	1751,7	87,489	1532,6															
Scenario 4	Change Manual VA to 6 Kiosks with 6 lines and 7 Bag Drops	Business VA	30,348	471,53	40,275	485,523	42,452	831,205															
		Manual VA	184,009	802,5	360,922	1071,9	471,269	1212,9															
		Bag Drop VA	204,792	962,1	366,698	1058,4	403,173	1106,1															
		Kiosk VA	0	0	0	0	0	0															
		Kiosk CU	0,48342	119,55	0,49166	169,466	0,37017	111,189															
		Bag Drop CU	90,438	1465,5	103,856	1521,3	97,881	1543,2															
Scenario 5	Change Manual VA to 6 Kiosks with 6 lines and 8 Bag Drops	Business VA	34,712	526,391	43,97	584,153	47,971	853,512															
		Manual VA	162,971	713,7	314,496	869,7	447,492	1201,8															
		Bag Drop VA	135,867	820,2	216,427	709,5	242,483	745,5															
		Kiosk VA	0	0	0	0	0	0															
		Kiosk CU	0,4083	160,516	0,49614	161,07	0,34502	117,845															
		Bag Drop CU	103,293	1514,4	98,421	1499,7	96,759	1498,2															
Scenario 6	Change Manual VA to 6 Kiosks with one serpentine line and 8 Bag Drops	Business VA	32,572	474,61	36,767	479,848	49,174	608,753							27,819	911,573	28,883	584,129	35,221	587,41	30,922	733,973	30,585
		Manual VA	119,016	823,5	253,519	1253,7	326,198	1344,9							166,267	607,8	160,529	677,1	182,607	829,2	174,69	707,7	185,107
		Bag Drop VA	123,218	601,5	210,427	920,7	234,882	993,3							131,957	437,1	135,524	633	130,225	402	147,429	627	207,511
		Kiosk VA	0	0	0	0	0	0							0	0	0	0	0	0	0	0	0
		Kiosk CU	0,42244	114,261	0,3514	106,827	0,45858	355,784							0,94074	252,319	1,765	450,774	0,23841	179,411	1,02788	241,971	1,7699
		Bag Drop CU	96,902	2146,5	107,223	1474,5	97,9	1554,3							176,299	2380,8	295,031	2446,5	82,524	1322,1	140,235	2085,3	180,053

Table 5. Results of the average and máximum waiting time at queues of different services.

Scenario	Changes in configuration/Increasing volume of Passengers	Service	X	Current situation - Base case Max Pax in Q	Nº Pax WT < X	Increasing 20% Demand VA Max Pax in Q	Nº Pax WT < X	Increasing 30% Demand VA Max Pax in Q	Nº Pax WT < X	Base Case + send pax from Manual to Kiosk VA Max Pax in Q	Nº Pax WT < X	% of Pax Redirected	Increasing 20% Demand in VA + send pax from Manual to Kiosk VA Max Pax in Q	Nº Pax WT < X	% of Pax Redirected	Increasing 30% Demand in VA + send pax from Manual to Kiosk VA Max Pax in Q	Nº Pax WT < X	% of Pax Redirected	Increasing 20% Demand CU Max Pax in Q	Nº Pax WT < X	Increasing 30% Demand CU Max Pax in Q	Nº Pax WT < X	Base Case + send pax from BagdropCU to BagdropVA Max Pax in Q	Nº Pax WT < X	% of Pax Redirected	Increasing 20% Demand CU + send pax from BagdropCU to BagdropVA Max Pax in Q	Nº Pax WT < X	% of Pax Redirected	Increasing 30% Demand CU + send pax from BagdropCU to BagdropVA Max Pax in Q	Nº Pax WT < X
Scenario 1	Base Case (6 Manuals & 6 Bag Drops)	Business VA	X = 180s	3	96,49%	3	94,99%	3	95,76%	2	29,67%		3	94,65%		3	95,75%		2	97,27%	2	94,31%				2	97,39%		2	96,90
		Manual VA	X = 480s	28	76,40%	42	61,57%	58	44,73%	22	62,89%	3,56%	26	68,73%	10,15%	28	54,79%	16,03%	22	90,42%	23	89,96%				19	89,12%		22	88,87
		Bag Drop VA	X = 300s	9	100,00%	9	100,00%	10	98,51%	6	100,00%		9	99,78%		15	93,93%		6	100,00%	9	100,00%				11	99,15%		13	97,66
		Kiosk VA	X = 60s	1	100,00%	1	100,00%	1	100,00%	1	99,87%		1	100,00%		1	100,00%		1	100,00%	1	100,00%				1	100,00%		1	100,00
		Kiosk CU	X = 60s	1	96,44%	1	92,81%	1	99,90%	1	99,88%		1	99,83%		1	99,71%		1	99,24%	1	99,27%				1	98,97%		1	99,16
		Bag Drop CU	X = 300s	19	87,55%	15	91,08%	17	92,23%	21	94,75%		19	92,54%		16	93,21%		33	80,95%	58	59,31%	16			24	86,42%	10,13%	24	79,58
Scenario 2	Change to Serpentine Line in Bag Drop CU	Business VA	X = 180s	3	97,15%	3	94,34%	3	93,59%	3	97,42%		3	96,85%		3	94,76%		3	97,32%	3	93,96%	3	97,64%		3	97,42%		3	97,51
		Manual VA	X = 480s	20	83,78%	42	59,56%	54	38,97%	20	85,23%	2,01%	27	55,53%	8,6%	29	44,95%	14,8%	23	80,50%	23	78,96%	22	82,14%		22	84,14%		23	82,24
		Bag Drop VA	X = 300s	9	100,00%	10	100,00%	10	100,00%	10	100,00%		11	99,60%		14	98,55%		10	100,00%	10	100,00%	10	100,00%		12	99,66%		18	95,89
		Kiosk VA	X = 60s	1	100,00%	1	100,00%	1	100,00%	1	100,00%		1	100,00%		1	100,00%		1	100,00%	1	96,77%	1	100,00%		1	100,00%		1	100,00
		Kiosk CU	X = 60s	1	99,72%	1	99,82%	1	99,78%	1	99,81%		1	99,71%		1	99,70%		1	99,47%	2	96,01%	1	99,69%		1	99,45%		2	99,23
		Bag Drop CU	X = 300s	20	89,96%	20	91,31%	22	91,79%	20	89,51%		21	91,21%		21	92,96%		26	68,25%	28	41,61%	19	96,89%	4,8%	22	91,45%	11,12%	22	89,80
Scenario 3	Change Manual VA to 6 Kiosks with one serpentine line and 7 Bag Drops	Business VA	X = 180s	3	97,49%	3	95,38%	3	94,99%																						
		Manual VA	X = 480s	17	96,62%	33	75,29%	47	54,13%																						
		Bag Drop VA	X = 300s	30	65,39%	43	51,33%	51	40,92%																						
		Kiosk VA	X = 60s	1	100,00%	1	100,00%	1	100,00%																						
		Kiosk CU	X = 60s	1	99,78%	1	99,66%	1	99,72%																						
		Bag Drop CU	X = 300s	16	94,24%	20	91,12%	15	94,99%																						
Scenario 4	Change Manual VA to 6 Kiosks with 6 lines and 7 Bag Drops	Business VA	X = 180s	3	97,22%	3	95,32%	3	92,32%																						
		Manual VA	X = 480s	18	88,62%	35	69,42%	38	51,32%																						
		Bag Drop VA	X = 300s	24	75,53%	39	43,31%	40	36,75%																						
		Kiosk VA	X = 60s	1	100,00%	1	100,00%	1	100,00%																						
		Kiosk CU	X = 60s	1	99,69%	1	99,78%	1	99,91%																						
		Bag Drop CU	X = 300s	15	94,03%	15	92,11%	16	93,33%																						
Scenario 5	Change Manual VA to 6 Kiosks with 6 lines and 8 Bag Drops	Business VA	X = 180s	3	96,5%	3	95,0%	3	94,7%																						
		Manual VA	X = 480s	17	88,1%	31	71,5%	42	54,7%																						
		Bag Drop VA	X = 300s	17	94,6%	29	77,2%	33	68,7%																						
		Kiosk VA	X = 60s	1	100,0%	1	100,0%	1	100,0%																						
		Kiosk CU	X = 60s	1	99,8%	1	99,7%	1	99,8%																						
		Bag Drop CU	X = 300s	17	92,2%	18	93,1%	16	92,9%																						
Scenario 6	Change Manual VA to 6 Kiosks with one serpentine line and 8 Bag Drops	Business VA	X = 180s	3	90,6%	3	96,3%	3	93,7%										3	97,70%	3	97,64%	3	96,12%		3	97,10%		3	97,02
		Manual VA	X = 480s	15	92,6%	30	81,7%	40	57,4%										14	98,30%	15	98,96%	16	96,47%		16	98,39%		15	96,90
		Bag Drop VA	X = 300s	16	86,7%	30	78,3%	33	71,0%										17	95,85%	19	94,44%	16	97,82%		22	90,43%		31	75,74
		Kiosk VA	X = 60s	1	100,0%	1	100,0%	1	100,0%										1	100,00%	1	100,00%	1	100,00%		1	100,00%		1	100,00
		Kiosk CU	X = 60s	1	93,1%	1	99,9%	1	99,8%										1	99,55%	1	99,15%	1	99,94%		1	99,44%		1	99,12
		Bag Drop CU	X = 300s	18	85,9%	19	91,7%	17	92,9%										30	81,23%	53	60,44%	17	95,21%	0,2%	24	87,96%	5,3%	24	81,88

Table 6. Results of the maximum number of people at queues, number of passengers waiting less than X seconds and % of passengers redirected to other serv

The analisis of the results in the table would lead to be able to compare the scenarios and situations and see the better configurations having lower waiting times and avoid overcrowding in order to increase the customer satisfaction.

Scenario 1 – Base Case

The base case corresponds to the current layout at the termirnal considering the number of passengers and times extracted from the data collection.

To bear in mind the actual connfiguraton, there are 16 check-in kiosks, 6 manual check-in desks and 6 bag drop counters in the VA area and 20 check-in kiosks and 8 automatic bag drops in the CU area.

While no modifying the base case if there is an increase in the demand for Virgin Australia the average and maximum waiting time at the queue as well as the maximum number of passengers at the queue at each of the services in this area increases as expected. While the demand is increased and so are the waiting times and the percentages of people waiting less than certain amount of minutes, is decreased.

In the automatic check-in kiosks, as mentioned before, there are no queues so there are no waiting times. As the capacity utilization of the kiosks is much more lower than the counters, it has been considered to send people from the manual check-in to the automatic kiosks when the manual's serpentine queue reaches more than 25 people. The results obtained show that a 3,5% of all the people going to the manual, have been redirect to use the kiosks in the base case which is not a lot but in case of having a 20% or 30% more demand a 10% and 16% are the percentages of passengers redirected, respectively. The number of passengers waiting in the counters' queue is then 26 and 28 instead of 42 and 58 before redirecting, respectively to the two increases of demand.

As explained in the fifth section, when introducing in the *Anylogic* program the comand of sending people to the kiosks if the number of passengers in manual queue is 25, there is a limitation that maybe some passengers are on their way to the queue and will be added to the previous 25. That is the reason why sometimes the maximum number of passengers in the queue can reach a little bit more than 25. It has been calculated that the maximum margin of error is usually arround this 10%.

Referring to the waiting times in the queue, redirecting in the base case means a reduction in the average waiting time at the manual line of half a minute, almost a minute

if increasing a 20% in demand and two minutes and a half if 30% increase. More people are using the kiosks but no queues are formed either so the waiting times remain to be inexistent.

These results can be graphically seen at the Graph 1.
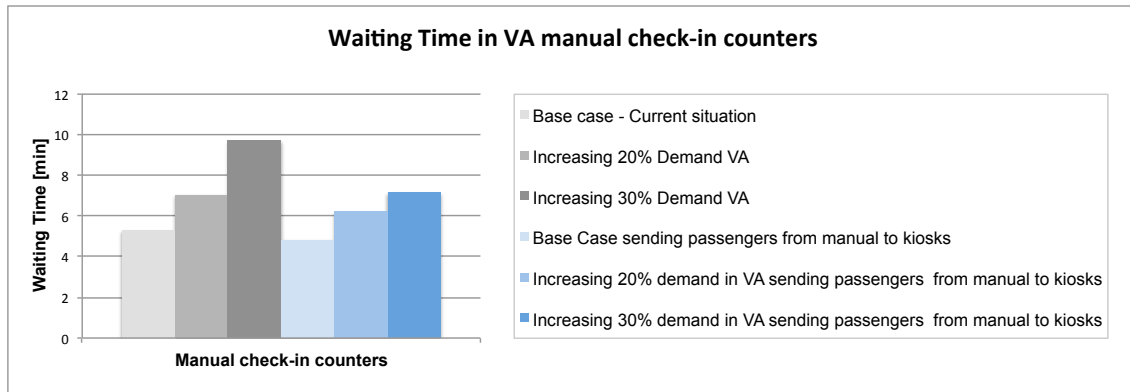
Graph 1. Waiting Time in VA manual check-in facility.

It should be noted that people that use the manual counters, are able to leave their luggage there so they go directly to the security point. Otherwise, the ones using the kiosks, need to go to the bag drop counters if they need to check any suitcaise.

For that reason, in the situation of redirecting people from the manual to the kioks would mean that more people will need to use the bad drop facilities. As shown in the results, the waiting time at bag drops with a 20% increase of demand is only 10 more seconds than before redirecting and the maximum number of people at queue remains the same. In case of the 30% increse in VA area, the increase is arround 42 seconds which is not considered huge but the maximum number of people waiting at the bag drop facilities changes from 10 to 15.

The next situation of the base case will be considering a 20 and 30% increase of demand but in the Comon User area.

The waiting time at the kiosks are negligible as there are around 2 seconds in average and the maximum average number of passengers in the queue is one. Promptly, some people waits for the service around 4 minutes in average increasing some seconds as increasing demand.

The bag drop in this sector experiments an increase of waiting time when studying the two possibles increases of demand, being 2 minutes for the base case, almost 3 minutes when 20% more people and almost 5 when 30%. Respectively, the maximum number of

customers in the line are 19, 33 and 58. That means a lot of people occupying a limited space so considering the possibility to send them to the Virgin Australia bag drop. It is also remarkable that with the 30% increase of demand more than a 40% of passengers are waiting more that 5 mins to be attended.

The further condition will be sending passengers from CU bag drop to the VA one when reaching a total amount of 18 passengers waiting in the 8 queues corresponding to the 8 bagdrops. In the base case, this is the maximum number of passengers reached at the line so there is never redirection. In case of 20% and 30% more customers arriving to that service, the waitings times are slightly reduced compared to the case of not redirecting and the waiting time at the VA bagdrop increases. The redirection would be a 10% and 13% of the bag drop common users, referring to 20% and 30% increased in demand, permitting to reduce considerably bag drop queues in that area but increasing a bit the one in the VA bagdrop.

The plots showing the waiting times at the bag drops of the two areas applying the redirection can be seen at the Graph 2.
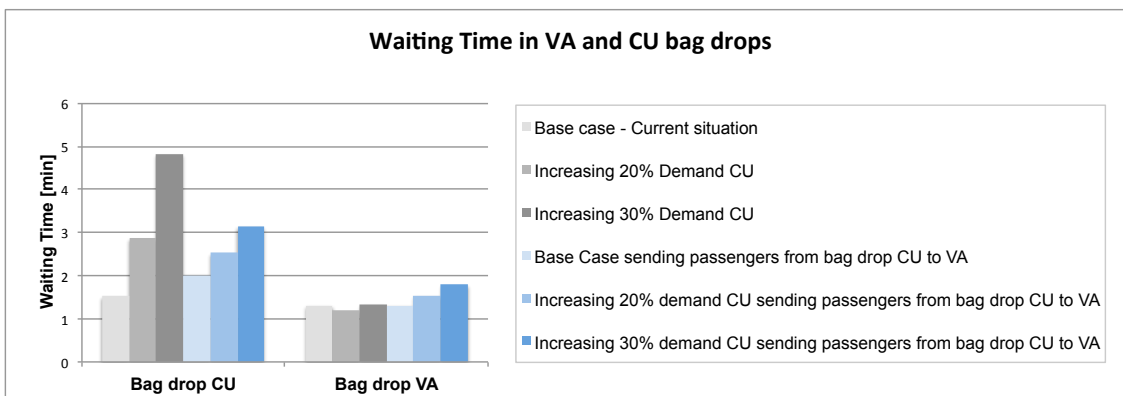
Graph 2. Waiting Time in VA and CU bag drops.

Scenario 2 – Change the 8 lines in the bag drop of CU to a unique serpentine one

As found in the literature review, previous works demonstrate the better performance of having a serpentine line instead of one for each of the services. The aim of this scenario thus, is to prove if a serpentine line in the bag drops helps to reduce both the waiting time and number of passengers waiting.

It should be noted that there is thought to be a limitation of space in that area but it will be

tested anyway to analyse the results and see if they improve in any of the situations.

When applying the queue change compared to the previous one, the average waiting time seems to increase in 1 minute and the maximum is considerably reduced. This reduction in the maximum wait time could be possible because of the extreme situations. In the case of one line for each bag drop, if one service point stops working, people normally wait until an airport worker fixes it so their waiting time increases. In this scenario, if this situation happens, the person can go to another service point without re-queuing, so the maximum would be much lower.

When increasing demand in the VA zone, as in the previous scenario, the service experimenting the more considerable increase in the waiting times at queue as well as the maximum number of passengers waiting is the manual check-in counters. In this case, it has been studied the situation of sending people to the underutilised kiosks, and some of them go later to the bag drops so the waiting times and queues increase very few in this facility. The average times increase in 2, 9 and 36 seconds respectively in the bag drop of VA.

On the other side, when increasing demand in the CU zone, the waiting times in the kiosks seem to be unaltered but they do in the bag drop. If comparing the bag drop with a unique serpentine line in the current situation with the situations of increasing demand, the results show that waiting times change from 2,5 minutes in the base case to 4 minutes if 20% more passengers and 5,5 minutes if the increment of demand is a 30%. In this case, the maximum waiting times are increased from 10 mins to 12 and 13 minutes, respectively.

Otherwise, if we compare these situations in the CU bag drop with the first scenario, the conclusions found are unexpected. The waiting times are increased and the reason could be the limitation of space mention before. The space where the serpentine is placed is not as long as needed, the people tend to accumulate there obstructing the entrance which causes confusion to other customers wanting to go to the queue and that lead to the increase in waiting times. In these cases, the maximum number of passengers waiting in the queue is considerably reduced with the serpentine line.

In the CU bag drop, the waiting times at the line as well as number of passengers standing to use the service increase considerable if increasing demand. For that reason, it has been proposed to give some thought to send people to the VA bag drop when the queue exceeds a certain number of individuals.

In the base case, the average waiting time was 2,5 minutes and when redirecting passengers it is reduced to 2 minutes. The percentage of redirection is almost a 5% of the people in the bag drop facility.

In the circumstances of 20% increase demand the waiting time is reduced in half and 11% of passengers redirected. Before, a 68% of them were waiting less than 5 minutes and now it improves to a 92%.

In the 30% increase demand; the reduction of waiting time is less than 2 minutes but thanks to the redirection that is about 16%, the percentage of people waiting less than 5 minutes changes from 42 to 90%.

When comparing the redirections of this scenario versus the first one, it is seen that, in general, the percentage of people that are redirected from the bag drop of CU to the bag drop of VA increase. That makes sense because including a serpentine line, being aware of the small space available in the area, implies that there is less capacity for passengers and more people will be redirected.

See in the Graph 3 the comparison of waiting times at que bag drop in CU with and without the serpentine line.
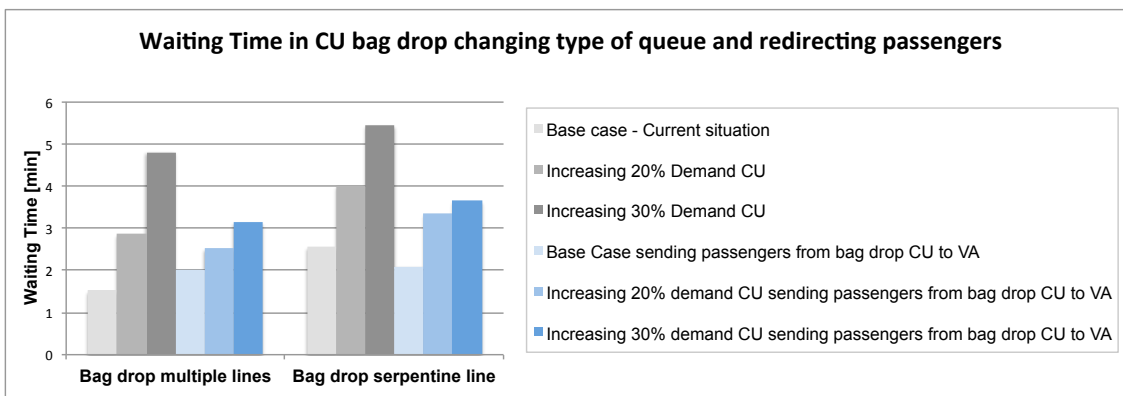
Graph 3. Waiting Time in CU bag drop.

Scenario 3 – Change 6 manual check-in counters in VA to 6 kiosks with a serpentine line and 7 bag drops counters

The next change made is to observe if the service at kiosks is faster than the traditional counters. The existing kiosks keep working the same way, but now, the serpentine queue that was for the check-in desks attended by an airport officer, will be for automatic kiosks.

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The two zones with kiosks for Virgin Australia are studied separately because the first one has almost no queues and usually working well and with the new one, the objective is to see the impact when substituting the manual.

Is has to be taken into account that the passengers using these new kiosks will go to the bag drop before reaching the security point so that facility will serve a major amount of users, that is why there will be opened 7 bag drop counters instead of the 6 that are in the base case.

The findings after the simulation are that the waiting time at the serpentine queue for the kiosks would be now around 2 minutes and was more than the double when having the counters. Also, the maximum delay time has been cut down in 5 minutes, from 18 minutes to 10.

The number of customers waiting has been lowered in 10 in average and the percentage of them waiting less than 8 minutes reaches now the 97% compared to a 76% before.

Taking a look at the bag drop where a new service has been opened from the base case, the waiting time has substantially increased from 1 minute to 4 and the customers at the queue too, from 9 to 30. The reason of that fact is the one mentioned before, the majority of passengers using the new kiosks will demand going to the bag drop causing this overcrowding.

If increasing a 20% or a 30% demand, the results tend to be similar, the waiting times and people waiting in the line are better for the kiosks placed instead manual counters but referring to the bag drops, this times and number of persons standing is even huge.

So the next step will be opening a new bag drop point, which will be considered one of the next scenarios. Also, it has been interested to study the results obtained if the serpentine line is changed to a line for each service, as it works in the existent kiosks.

Scenario 4 – Change 6 manual check-in counters in VA to 6 kiosks with 6 lines and 7 bag drops counters

As commented, in this scenario will be tested how the new kiosks work using different lines instead of a unique one.

Looking at the numbers obtained, the waiting time for the check–in in the new kiosks are increased compared to the previous scenario were there was a unique line, but,

decreased if we compare it to the base case of having check-in desks instead of automatic kiosks. The results for the waiting times are around 5 minutes for the previous counters that work with serpentine type of line, 2 minutes when substituting them with kiosks and finally 3 minutes if changing the type of queue.

The maximums wait times spent are in the order mentioned above: 18, 10 and 13 minutes.

In the Graph 4 are plotted the waiting times related to the kiosks with different types of queues.
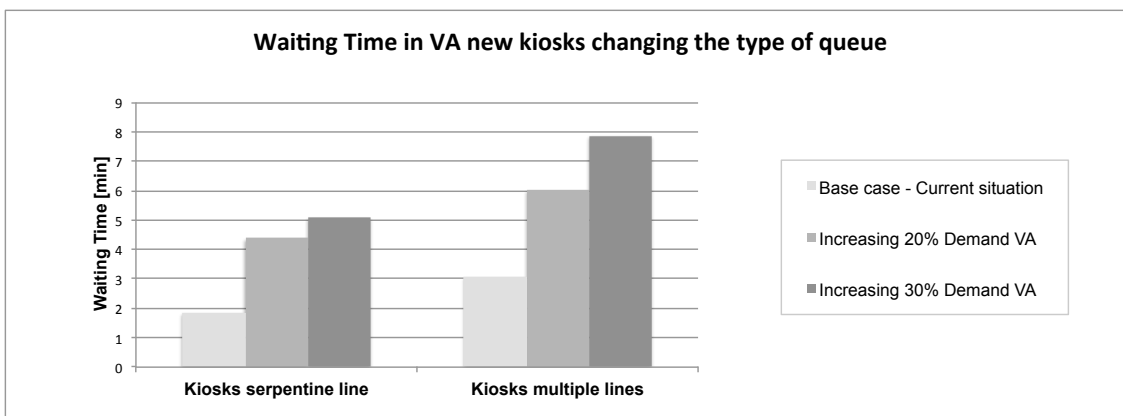
Graph 4. Waiting Time in VA kiosks.

The highest number of customers at the line of this service is lower for the kiosks than manual counters and is higher the percentage of those waiting less than 8 minutes.

All this, leads to the conclusion that kiosks give a faster service so will increase customer satisfaction. Using a serpentine line for these kiosks placed where there was a previous one but for the manual service, meaning that there is enough space, also improves the results obtained.

It should be mentioned that for the existent kiosks placed in the entrance, the space is restricted because of the columns so there is no chance to try to use a serpentine line there.

Scenario 5 – Change 6 manual check-in counters in VA to 6 kiosks with a serpentine line and 8 bag drops counters

As seen before the waiting times for the check-in do not improve with separate lines for

each service, but in this scenario it will be tried to improve the waiting at the bag drop adding one more point.

The average waiting time before adding that point was 3,5 minutes and now is reduced to 2 minutes. Taking into account the possible increase in demand of a 20% of the current one, the waiting time is obviously higher for higher demand but seem to be reduced if adding the new bag drop from 6 to 3,5 minutes and from almost 7 to 4 minutes if 30% demand increasing.

Also the number of people at the queue increases while there are more passengers using the facilities, but for each case of demand they tend to be less if there is one more bag drop in use.

Scenario 6 – Change 6 manual check-in counters in VA to 6 kiosks with a serpentine line and 8 bag drops counters

As it has been appreciated in the previous scenarios, when changing counters to kiosks, the bag drop needs to attend more passengers so a new service will be opened.

The waiting time at the serpentine for the base case as well as having 20 or 30% increase of demand in that area, tend to be similar that the ones obtained in the third scenario (Change 6 manual check-in counters in VA to 6 kiosks with a serpentine line and 7 bag drops counters). Also the maximum number of minutes spent there looks alike.

As expected, the relevant differences would be in the bag drop as opening a new point service. Comparing then the numbers for the waiting times, they are considerably lower. For the base case, 20% and 30% more customers in VA the times in case of having 7 bag drops are almost 4 minutes, 5 and 6 and with 8 service points they turn to 2, 3 and 4 minutes so for each case of demand, adding a bag drop counter would mean reducing in one minute the time spent at the queue. Also the maximums times are reduced.

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Go to Graph 5 to observe the results of having 7 or 8 bag drops.

Waiting Time in VA bag drop with different number of services
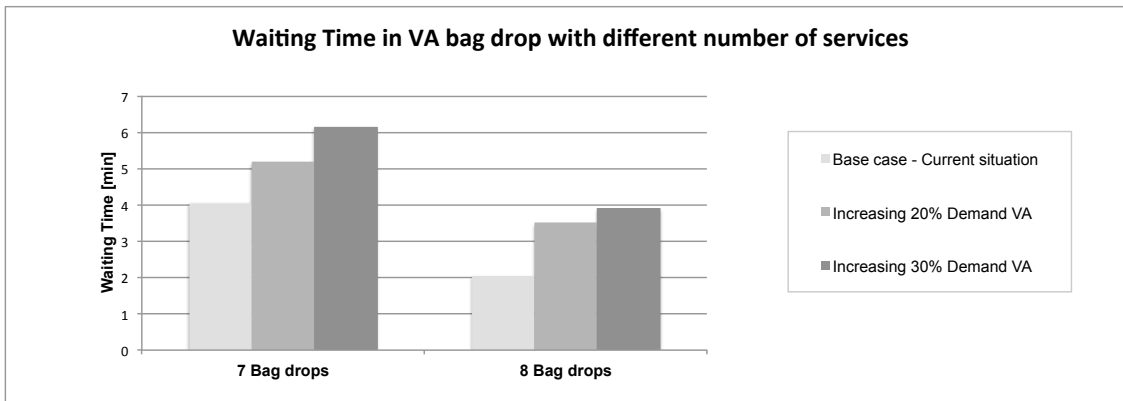
Graph 5. Waiting Time in VA bag drops.

As logical, the maximum number of passengers at the queue when increasing demand increases in both services, check-in and bag drop. This number as expected is much more lower in the bag drop when having 8 services opened instead of 7. The percentage of people waiting less than 5 minutes also changes considerably when adding a bag drop. It was only a 65%, 51% and 40% in the three situations of demand, and now will be 86%, 78% and 71% with the new service in operation.

As the results obtained in this scenario are considered good and easy to implement in the Brisbane terminal, more situations have been studied. These correspond to simulate different cases of increasing demand in the CU area and, as it has been previously analysed in the first scenario, redirect people to use any service of VA area, if necessary.

The figures obtained for the waiting times are the double in case 20% more passengers versus the actual number, and if the increase is 30% compared to the current demand the times are almost triple. This applied either to the check-in kiosks neither the bag drops. Is worth it to mention that as seen before the times waiting at the kiosks are low (half minute, 1 minute and 1,5 minutes in the 3 demand situations) and not so for the bag drop which are 1,5 minutes and almost 3 and 5 minutes if 20% or 30% more demand.

The maximum number of passengers at the check-in facilities as well as the percentages of those waiting less than 1 minute, remain the same: never queues are formed so none of the customers has to wait for the service.

In case of the bag drop that maximum amount of individuals waiting changes from 18 in the base case to 30 and 53 if increasing demand. Consequently, the percentages waiting less than 5 minutes is reduced from 85% to 81% and 60%, respectively.

Noticing the large number of passengers in the queue when increasing demand, the next case considered object of study would be redirecting some of these passengers to the VA facilities if exceeding 25 individuals in total in all the lines.

The change in waiting times at the VA bag drops because the increase of passengers experimented sent from the CU bag drop are graphically shown in the Graph 6.
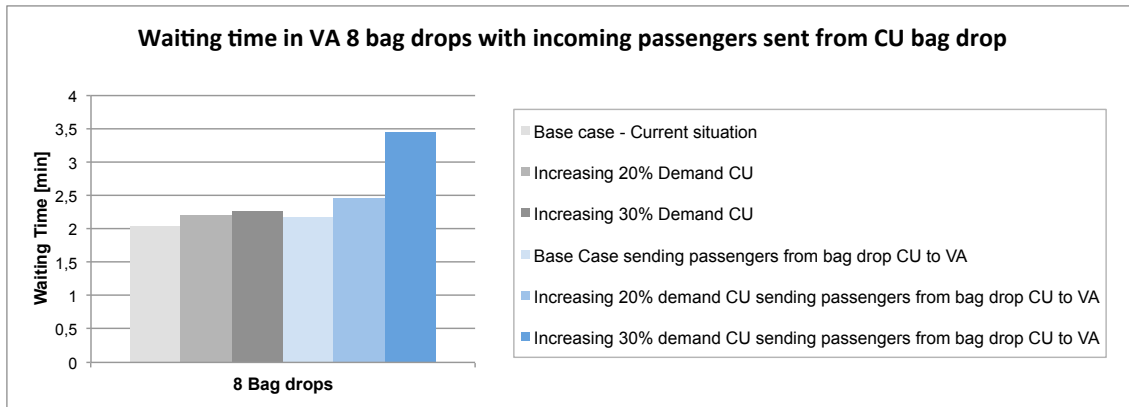
Graph 6. Waiting Time in VA bag drops.

In the base case the redirection is inappreciable but when there are 20% more of passengers, a 5,3% arriving to the bag drop are redirected and an 11% when demand increases in a 30%. In these three cases of demand, the rate of those waiting less than 5 minutes is respectively 95%, 88% and 82%, which seems a reasonable result.

Taking a look to the values of wait times redirecting passengers compared to the previous situation when not, for the 20% and 30% situations of more demand they are reduced in half a minute and a minute and a half, specifically.

6.2. Possible recommendations

As mentioned before, a previous study has been carried out in which it is decided whether the queue type of the new kiosks placed in the VA area will continue to be serpentine as before or will be changed to one line for each kiosk. In addition, due to the increase in number of kiosk, the number of people who, after checking in, will go to the bag drop will increase considerably and, in order to maintain the quality of service and the number of people served, the number of bag drop points will have to be increased.

After the different simulations have been carried out, the final configurations have been defined.

The scenarios 3,4,5 and 6 refer to the study mentioned and, as it is seen in the results, the type of queue that permits obtaining better results is one serpentine for the six kiosks and, in reference to the second decision, two extra bag drops seems to be the best option. Being aware of the cost minimization, having a total of 7 bag drops could have been a good option in terms of number of people served, but the waiting times and the number of people in the queue (indicators that have been decisive for this project) get worse and is necessary to keep in mind that customer satisfaction is above costs.

So, the final decision for this previous study has been to choose the scenario number 6 and compare it with the first and the second scenario in a wide range of situations.

Some of the results obtained are compared in the graphs added in the Graphs 7 and 8.
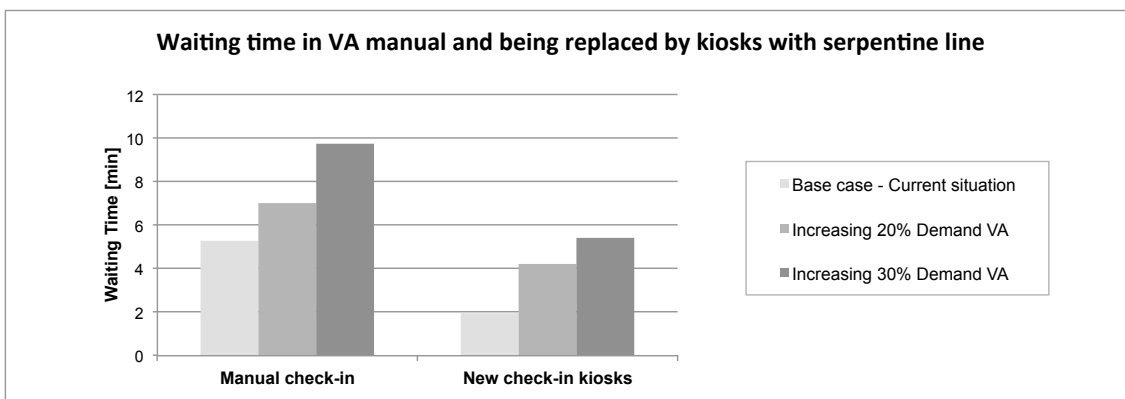
Graph 7. Waiting Time in VA manual check-in facility and new kiosks.
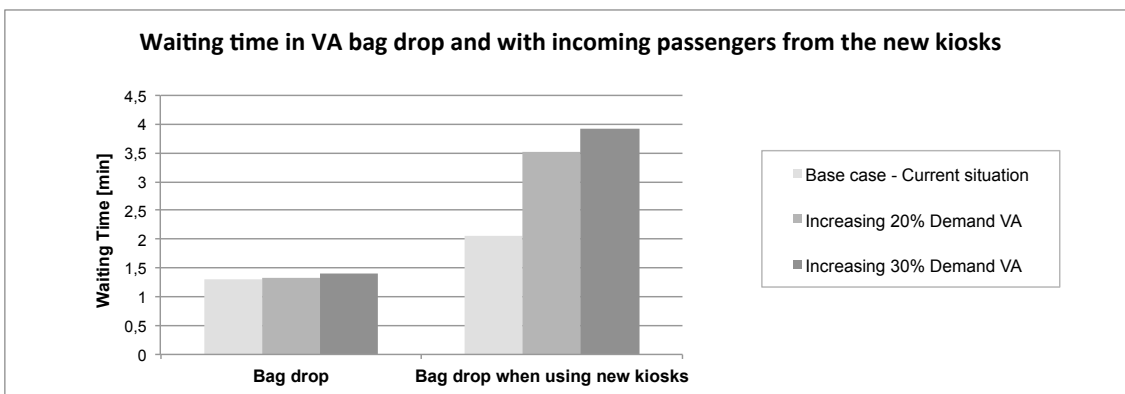
Graph 8. Waiting Time in VA manual check-in facility.

There is also considered the possibility of redirecting people between the facilities, specifically when increasing demand in CU and the bag drop gets crowded sending passengers to the VA bag drop facilities. These results are plotted in the Graph 9.

Waiting time in VA bag drop with incoming passengers from new kiosks and from CU

- Base case - Current situation
- Increasing 20% Demand CU
- Increasing 30% Demand CU
- Base Case sending passengers from bag drop CU to VA
- Increasing 20% demand CU sending passengers from bag drop CU to VA
- Increasing 30% demand CU sending passengers from bag drop CU to VA

Bag drop when using new kiosks
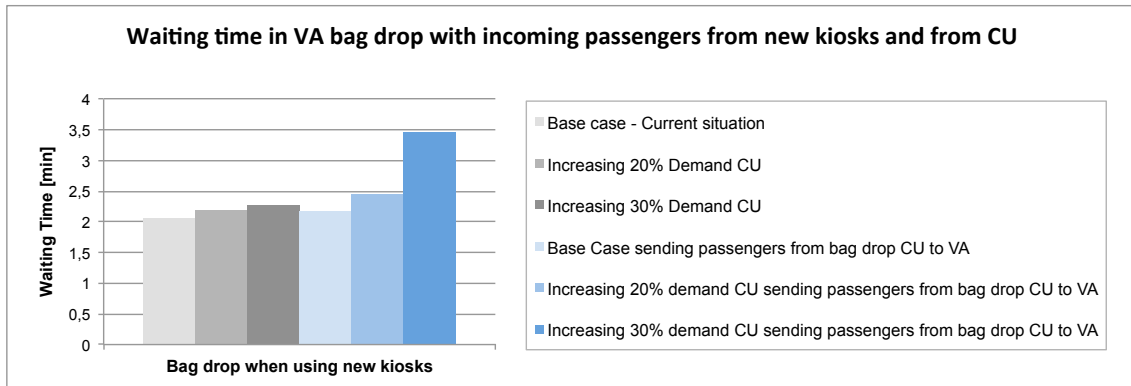
Graph 9. Waiting Time in VA bag drop.

Then, to continue through the final recommendations, it is seen than in a normal situation, a serpentine line is highly more recommended than one line for each service point. In this case, in the second scenario where has been tried to include this concept, it has been noted that the current space available was not enough for a serpentine line with the capacity needed and, furthermore, it leads to collusion of some of the passengers. Thus, for the near future is not recommended to implement the second scenario but, as it is expected an expansion in the terminal, the BAC will have to take into account it for the new plans of renovation.

Finally, with the third scenario a great improvement of all the studied Key Performance Indicators is obtained compared to the base case and would be the best option not only because of the comfort offered to passengers and the optimization of the space made, but also by the quality service that can be offered to customers.

7. BUDGET

The project budget has two different types of costs:

- Cost of human resources: The costs related to the work performed by the staff are quantified. The economic valuation of these resources takes into account the hours of dedication according to the corresponding hourly rate.
- Cost of material resources: It quantifies the cost of using computer equipment, office supplies and telephone costs, among others.

In the following sections will be detailed the parts of each of the costs mentioned.

7.1. Cost of Human Resources

The calculation is structured taking into account the following three aspects:

- Phases of the project in its elaboration process:
  - Search for the information. This phase includes the time devoted to the consultation of all the information necessary for the preparation of the project.
  - Information processing & Analysis of the current situation. Refer to the hours needed to select, sort and exploit the information to get results with it.
  - Development of different simulation models. It includes the time allocated for processing, simulation and subsequent analysis of the results.
  - Comparison of the results and review. Validation of the results obtained in each of the simulation models.
  - Writing & closure of the project.
- Assignment of hours to each of these phases
- Category of the different personnel that participated in each of them

Table 7 shows the costs of human resources, structured according to the project phase, the hours spent, and the personnel involved. The work has been carried out during 6 months with 133 business days which represents a total of 1064 hours.

Phase	Staff	Time [h]	Rate [€/h]	Total [€]
Search for the information	Engineer Jr.	192	25	6.912
Information processing & Analysis of the current situation	Engineer Jr.	100	25	3.600
	Consultant	108	50	7.776
Development of different simulation models	Consultant	280	50	20.160
Comparison of the results and review	Consultant	296	50	21.312
Writing & closure of the project	Engineer Jr.	88	25	3.168
TOTAL		**1.064**	**-**	**43.700**

Table 7. Costs of human resources.

7.2. Cost of Material Resources

The calculation has been broken down taking into account the following elements and is shown in Table 8:

- Computer hardware. Laptop, Analysis & Simulation programs.
- Office supplies. Printer paper, photocopies, USB's, etc.
- Communications. Phone, Cameras.

Concept	Total [€]
Computer hardware	1.500
Office supplies	400
Communications	160
TOTAL	**2.060**

Table 8. Costs of material resources.

7.3. Total cost of the project

The total cost of the project is obtained from the sum of the partial costs of human and material resources, taking into account a profit margin of 20% and the VAT and is detailed at Table 9.

Concept	Total [€]
Cost of Human Resources	43.700
Cost of Material Resources	2.060
Total 1	45.760
Industrial Benefit (20%)	9.152
Total 2 = Total 1 + Industrial Benefit	54.912
IVA (21%)	11.531,52
Total 3 = Total 2 + IVA	66.443,52

Table 9. Total costs.

The total budget for the project amounts (with VAT) to 66.443,52 €.

8. EVIRONMENTAL IMPACT

Once the improvements recommended in this project are implemented, the number of people waiting in the queues will be reduced meaning that the common zones will be less crowded on a certain moment. For that reason, it will be possible to reduce the amount of electricity used for the conditioning system in summer and the heating system in winter. The reduction of number of people in the area allows decreasing the consumption of electrical energy, which means also cutting down the contamination.

Another factor contributing to the environmental impact is the usage of computers during the performance of this project.

The laptops used by the engineers are made off metals and chemicals that contribute to global warming. The contamination of the computers is focused on two aspects:

- The fabrication of the components: One study the University of Arizona estimated that between 227 and 270 kilograms of carbon dioxide are emitted when making a laptop, much more than it is going to emit for its electrical consumption throughout its useful life. In addition, most computer components factories are located in Asian countries where environmental controls are more lax, not to mention that having to transport them from the other end of the world also causes a plus of pollution.

- Electricity consumption: Focusing mainly on the production of electricity it indirectly produces pollution. Nowadays much of the electricity comes from thermal or nuclear power plants instead of renewables energies. This would be the point where it would affect the efficiency of computers. A study carried out estimates that the emissions are 0,166 kg CO_2 / KWh. The laptops used during this project represent a consumption estimated in 65 W (0,065 KW) and reaches an amount of 1064 hours. Finally the emissions of CO_2 per computer will be 11,48 kg of CO_2.

- Finally in Table 10 there is an estimation of the contamination due to computers

Concept	Kg of CO_2 per computer	Kg of CO_2 per two computers
Average emissions of CO_2 in the fabrication of laptop's components	248,5	491
Estimated emissions due to electricity consumption of laptops	11,48	22,96
Total	**259,98**	**513,96**

Table 10. Emissions of CO_2.

CONCLUSIONS

The Brisbane Airport is considering different ways of improving the check-in and the bag drop areas of the Domestic Terminal to achieve a better quality service rate and increase customer satisfaction as it is predicted an increment of passengers in the near future.

The current system has been studied and an exhausted analysis of the data has been carried out to be able to construct different scenarios using a simulation program called *Anylogic.* The simulation of scenarios brings the opportunity to understand possible situations to be implemented by the Brisbane Airport Corporation. The more the representation made by *Anylogic* resembles reality, the more reliable will be the results obtained.

To compare the results some Key Performance Indicators have been analyzed in each of the cases. To decrease the average waiting time and the maximum waiting time, along with the decrease in the maximum number of passengers in the queue are some of the objectives. Also, it has been counted the percentage of passengers that wait less than a certain time at the queue. It is considered a parameter that can help with the ones mentioned before in order to improve the level of service.

As results show that the manual check-in is one of the most concured services and that the BAC is interested in automate the terminal in the following years, it has been proposed to change the current desks in Virgin Australia to automated kiosks but maintaining one serpentine line for all the services as it helps reducing waiting time. As more kiosks are operating, more passengers will need to go to the bag drop so it will be recommended to open two more service points to leave the luggage. (Scenario 6)

In order to compare scenarios, different situations of demand have been tested and it has been considered necessary in some situations the redirection of passengers between the different facilities if the current service is very crowded to help to improve the Key Performance Indicators.

In conclusion this thesis achieves, using a simulation tool, the pursuit of implementing the new technologies in the terminal, contribute in a positive way to minimize the cost, optimize the space and, the most important goal, provide a better quality of service to users. The obtained results of the simulation will help the Brisbane Airport to visualize and apply the possible improvements.

The next steps of this project would include the study of possible new scenarios in order

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to maintain one or two manual counters check-in services points in Virgin Australia as the BAC is interested in small changes so the passengers can assimilate them. It has been noted that elderly people tend to go to the manual check-in but based on the intentions of the airport, they will have to learn how to use the kiosk. Thanks to previous studies about this topic it has been observed that once they try to do the check-in in the kiosk successfully, they tend to use it more often.

Furthermore, if Brisbane Airport overreaches its targets of increasing the number of arriving flights, there is the possibility of having an increase of demand in both of the areas (CU & VA) at the same time and it will be important to analyze other options different from redirecting people. Installing more facilities and expanding these areas should be the first points to keep in mind.

AKNOWLEDGEMENTS

We would like to thank the University of Queensland for the opportunity has given to us to participate in a real project, providing us with the necessary assistance for the procedures so that two students of the ETSEIB can participate actively in the university.

SangHyung Ahn has been the tutor who has done the follow up and has put us in contact with the BAC to be able to realize the improvements according to the established bases.

On the other hand, without the time that the BAC has dedicated us to explain the situation, its interests and the objectives that are proposed for the next years the project would not have gone ahead. In addition, the data provided, together with their opinions based on real facts, have helped us to understand the problems that a corporation has with such responsibility.

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APPENDIX

Section 1. Distribution plots.

In the plots below extracted from *@Risk*, it is possible to find the relation between the data collected and the distribution that best fits with it. The histogram shown in blue represents the data of times extracted from the videos, the red line represents the distribution that most resembles the histogram.

As mention in the thesis, the distributions have different possibilities to be ranked and the selected one has been the AIC. So the program will show the distributions that best fit in order of best value according to this rank. The first one is the one that has been selected.

It is also shown in the pictures, an statistics grid with the values of some of the parametres as the maximum, minimum, mean or standard deviation of the data.

Finally, the plots obtained for the different facilities and areas at the airport are presented down below.

<u>CU area:</u>

- The TBA of the check-in kiosks

- The ST of the check-in kiosk

Fit Comparison for CU Service time Check In
RiskLognorm2(4.4007,0.70238)

Rank By: AIC

Fit	Value
☑ Lognorm2	3108.9282
☐ Loglogistic	3112.6809
☐ Invgauss	3114.1565
☐ Weibull	3140.4201
☐ Expon	3204.8654
☐ Triang	3365.6749
☐ Levy	3380.0123
☐ Uniform	3651.5269
☐ BetaGeneral	N/A
☐ Kumaraswamy	N/A
☐ Pareto	N/A

5.0% / 90.0% / 5.0%
4.4% / 90.6% / 5.1%

Statistics Grid

	Input	Lognorm2
Minimum	10.80	0.00
Maximum	615.03	+∞
Mean	103.42	104.31
Mode	≈60.64	49.77
Median	82.60	81.51
Std Dev	77.45	83.30
Skewness	2.1892	2.9052
Kurtosis	10.8761	21.0277
Left X	25	25
Left P	5.0%	4.4%
Right X	258	258
Right P	95.0%	94.9%
Dif. X	233.03	233.03
Dif. P	90.0%	90.6%
1%	14.56	15.91
5%	24.53	25.67
10%	32.30	33.13
15%	40.03	39.36
20%	47.90	45.13
25%	53.63	50.75
30%	58.13	56.39
35%	61.36	62.18
40%	70.97	68.22
45%	75.93	74.62
50%	82.60	81.51
55%	89.44	89.03
60%	96.60	97.38
65%	106.50	106.84
70%	116.46	117.80
75%	134.50	130.90
80%	150.46	147.21
85%	166.30	168.79
90%	199.54	200.50
95%	257.56	258.79
99%	383.90	417.67

@RISK Trial Version — For Evaluation Purposes Only

- The TBA of the automatic bag drop

@RISK - Fit Results:3

Fit Comparison for CU TBA bag drop
RiskExpon(132.43)

Rank By: AIC

Fit	Value
☑ Expon	2580.1233
☐ Triang	2648.1563
☐ Uniform	2791.3313
☐ BetaGeneral	N/A
☐ Gamma	N/A
☐ Invgauss	N/A
☐ Kumaraswamy	N/A
☐ Levy	N/A
☐ Loglogistic	N/A
☐ Lognorm	N/A
☐ Pareto	N/A
☐ Pearson5	N/A
☐ Pearson6	N/A
☐ Weibull	N/A

5.0% / 90.0% / 5.0%
3.8% / 92.0% / 4.2%

Statistics Grid

	Input	Expon
Minimum	0.00	0.00
Maximum	580.40	+∞
Mean	132.43	132.43
Mode	≈48.62	0.00
Median	96.23	91.79
Std Dev	130.97	132.43
Skewness	1.6811	2.0000
Kurtosis	5.4017	9.0000
Left X	5	5
Left P	5.0%	3.8%
Right X	419	419
Right P	95.0%	95.8%
Dif. X	413.66	413.66
Dif. P	90.0%	92.0%
1%	1.33	1.33
5%	5.07	6.79
10%	14.84	13.95
15%	23.60	21.52
20%	37.80	29.55
25%	45.46	38.10
30%	48.73	47.23
35%	57.43	57.05
40%	68.62	67.65
45%	86.67	79.17
50%	96.23	91.79
55%	104.07	105.75
60%	113.37	121.34
65%	124.83	139.03
70%	150.67	159.44
75%	166.00	183.59
80%	189.37	213.14
85%	242.84	251.24
90%	359.60	304.93
95%	418.73	396.72
99%	562.30	609.86

@RISK Trial Version — For Evaluation Purposes Only

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- The ST of the automatic bag drop

VA area:

- The TBA of the check-in kiosks

Fit Comparison for VA TBA check in kiosks
RiskGamma(2.4882,72.208)

Rank By	AIC
Fit	Value
☑ Gamma	1505.6934
☐ Weibull	1507.6903
☐ Lognorm	1517.8752
☐ Triang	1527.3252
☐ Invgauss	1532.1086
☐ Expon	1549.8146
☐ Uniform	1602.2417
☐ Levy	1640.7186
☐ BetaGeneral	N/A
☐ Kumaraswamy	N/A
☐ Pareto	N/A

Statistics Grid

	Input	Gamma
Minimum	12.40	0.00
Maximum	597.53	+∞
Mean	179.67	179.67
Mode	≈171.03	107.46
Median	150.76	156.26
Std Dev	113.39	113.90
Skewness	1.1881	1.2679
Kurtosis	4.4217	5.4114
Left X	38	38
Left P	5.0%	4.3%
Right X	403	403
Right P	95.0%	95.2%
Dif. X	365.00	365.00
Dif. P	90.0%	91.0%
1%	14.67	19.77
5%	37.96	40.96
10%	64.04	57.65
15%	81.60	71.43
20%	91.94	83.97
25%	100.63	95.91
30%	109.67	107.61
35%	118.37	119.31
40%	128.77	131.20
45%	139.00	143.46
50%	150.76	156.26
55%	164.87	169.81
60%	177.56	184.36
65%	189.20	200.25
70%	212.13	217.95
75%	234.80	238.17
80%	252.37	262.08
85%	303.00	291.84
90%	345.67	332.25
95%	402.96	398.37
99%	510.47	543.17

Legend values on chart: 5.0% | 90.0% | 5.0% ; 4.3% | 91.0% | 4.8% ; markers at 38 and 403

@RISK Trial Version
For Evaluation Purposes Only

- The ST of the check-in kiosks

Fit Comparison for VA ST check in kiosks
RiskGamma(3.7266,31.554)

Rank By	AIC
Fit	Value
☑ Gamma	1623.0462
☐ Weibull	1624.4783
☐ Loglogistic	1626.3218
☐ Lognorm	1642.8559
☐ Triang	1647.2100
☐ Invgauss	1664.6505
☐ Pearson5	1700.1950
☐ Pearson6	1702.2781
☐ Expon	1720.6504
☐ Uniform	1745.1769
☐ Levy	1837.8226
☐ BetaGeneral	N/A
☐ Kumaraswamy	N/A
☐ Pareto	N/A

Statistics Grid

	Input	Gamma
Minimum	9.34	0.00
Maximum	344.73	+∞
Mean	117.59	117.59
Mode	≈117.94	86.04
Median	107.07	107.25
Std Dev	59.27	60.91
Skewness	1.0348	1.0360
Kurtosis	4.4968	4.6100
Left X	42.4	42.4
Left P	5.0%	6.7%
Right X	235.6	235.6
Right P	95.0%	95.3%
Dif. X	193.20	193.20
Dif. P	90.0%	88.7%
1%	10.14	22.39
5%	42.40	38.18
10%	52.87	49.34
15%	60.23	58.09
20%	69.40	65.79
25%	77.83	72.93
30%	85.67	79.80
35%	87.34	86.55
40%	93.80	93.30
45%	101.80	100.17
50%	107.07	107.25
55%	114.73	114.67
60%	123.27	122.55
65%	128.73	131.06
70%	136.63	140.44
75%	145.56	151.05
80%	157.60	163.47
85%	175.27	178.76
90%	202.97	199.25
95%	235.60	232.30
99%	300.76	303.12

Legend values on chart: 5.0% | 90.0% | 5.0% ; 6.7% | 88.7% | 4.7% ; markers at 42.4 and 235.6

@RISK Trial Version
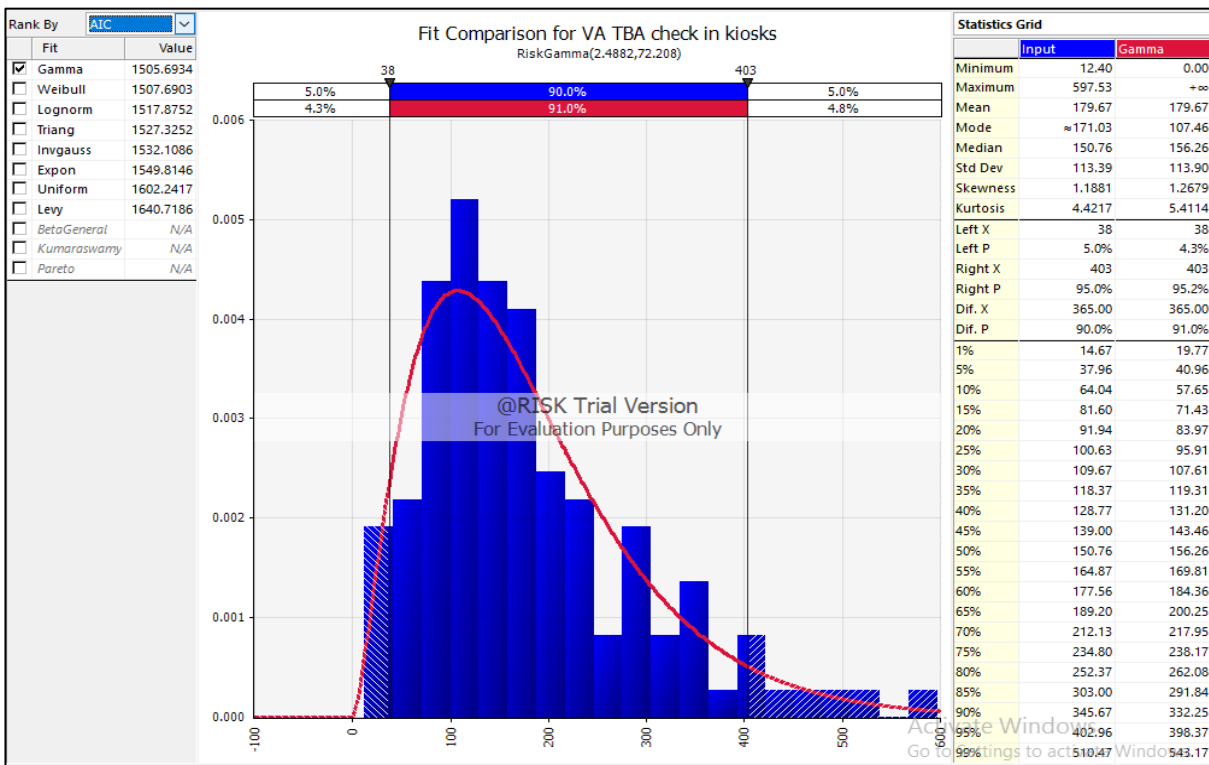For Evaluation Purposes Only

- The TBA of the manual check-in counters

- The ST of the manual check-in counters

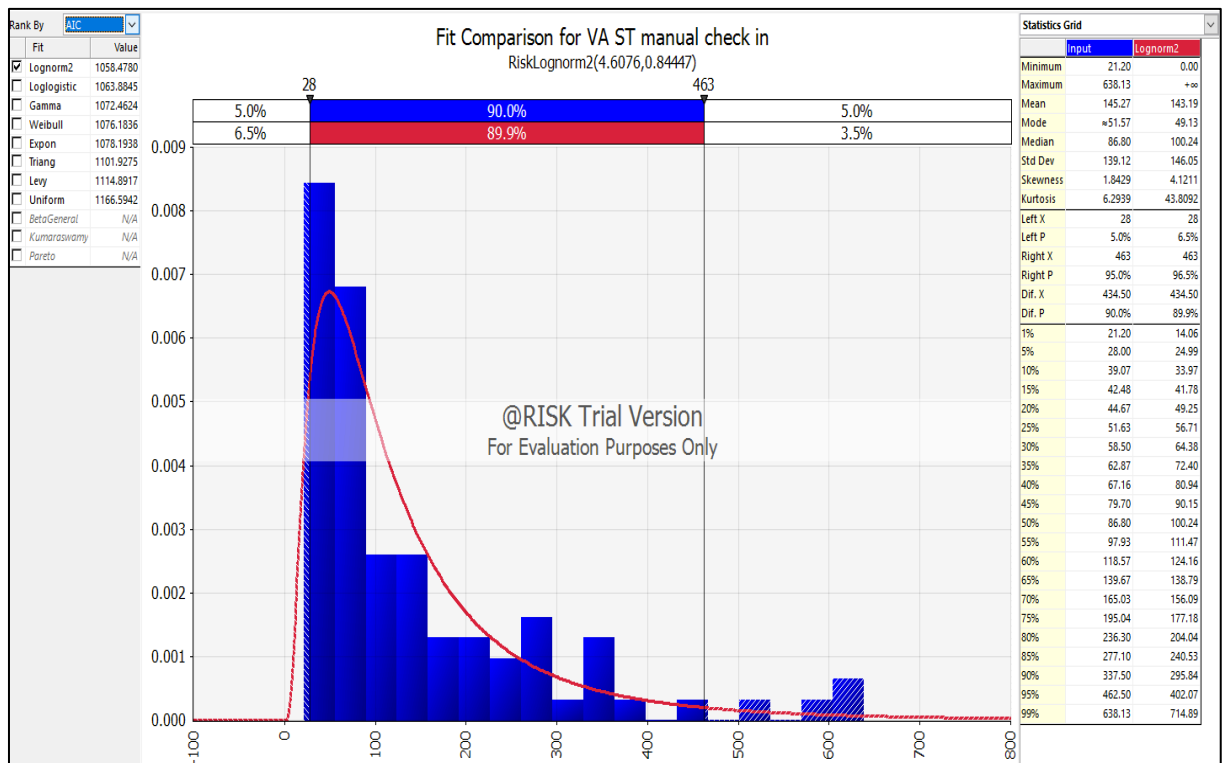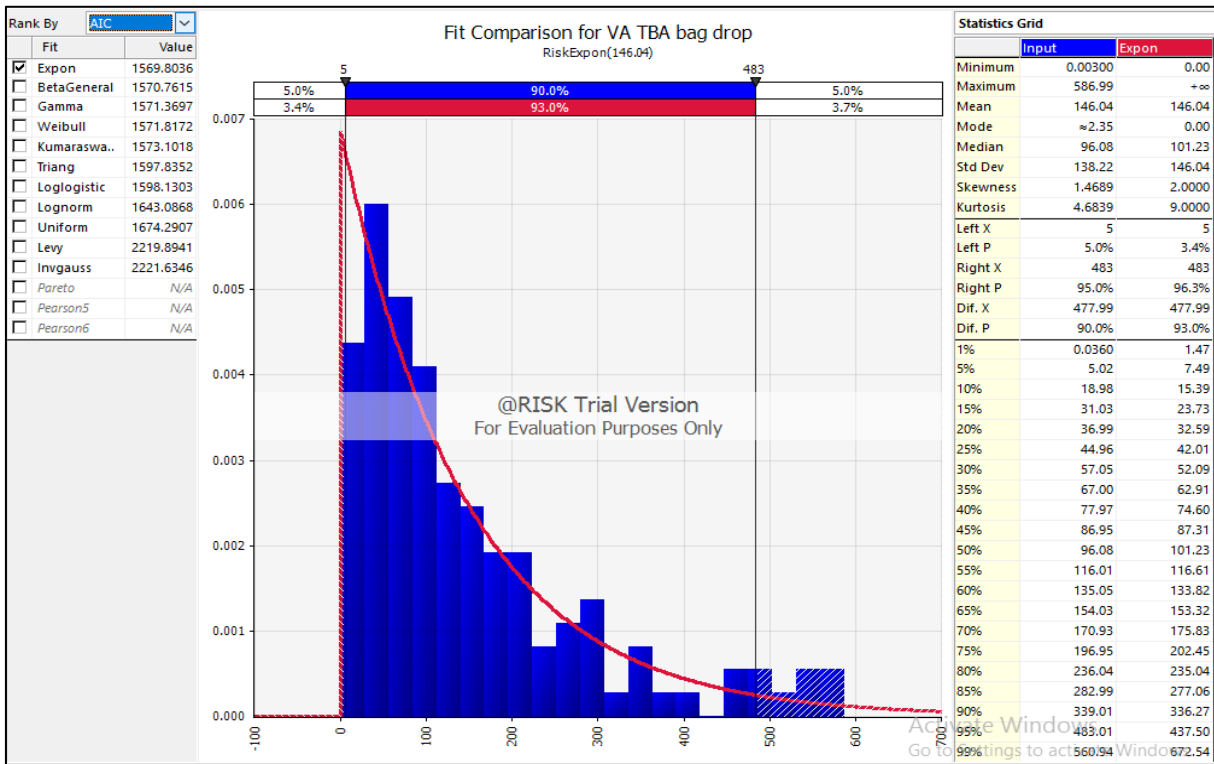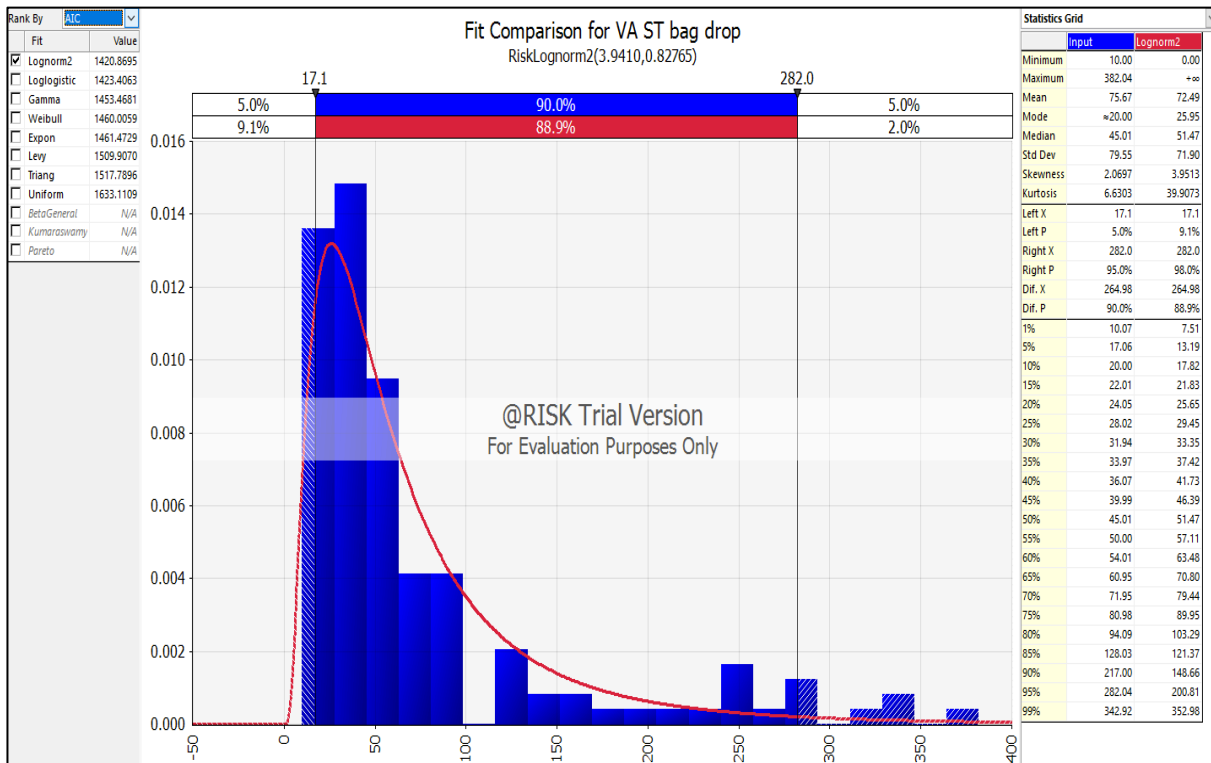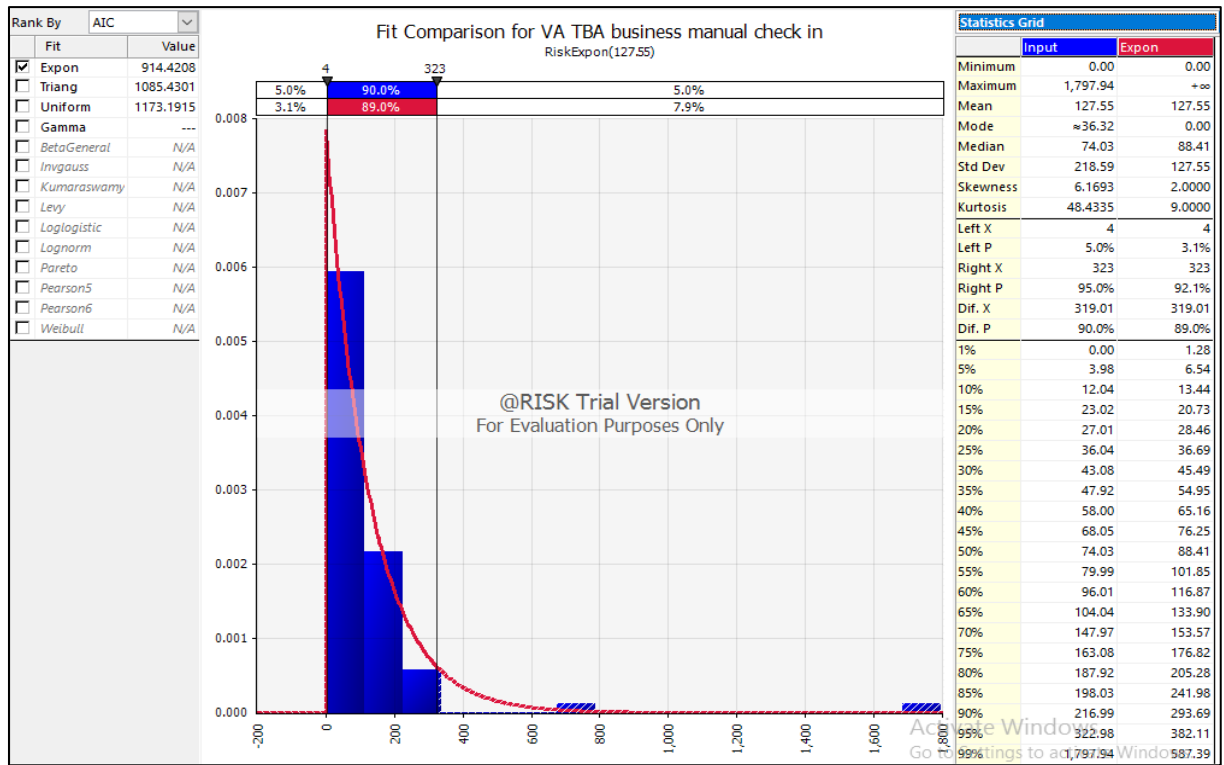- The BA of the bag drop counters

- The ST of the bag drop counters

- The TBA of the business check-in counters

- The ST of the business check-in counters