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Efficient use of airport resources: optimizing the airport check-in counter allocation problem

DISSERTAÇÃO DE MESTRADO

Thesis presented to the Programa de Pós-Graduação em Engenharia de Produção of the Departamento de Engenharia Industrial, PUC-Rio as partial fulfillment of the requirements for the degree of Master em Engenharia de Produção.

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Abstract

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This dissertation deals with the Airport Check-in Counter Allocation Problem (ACCAP). The check-in process is one of the most problematic airport services. Inefficient check-in processes propagate problems as a bullwhip effect being the basis for low quality service levels. Moreover, check-in counters usually occupy a considerable area in airports affecting concession revenues. An efficient check-in process may therefore contribute to reduce airport costs and increase service level. This work presents a new methodology to optimize the ACCAP that combines optimization and simulation. The objective is to determine the optimal number, schedule and location of check-in counters assigned to departing flights, such that operational costs are minimized and a given service level is ensured. The methodology is composed of three steps. Step 1 uses optimization models to determine the optimal number of desks. Step 2 uses simulation to assess if the results obtained in Step 1 meet the service level. Step 3 uses an optimization model to enforce an adjacent constraint for dedicated check-in systems. For Step 1 it is developed two new optimization models for common and dedicated check-in systems that include constraints regarding the utilization factor concept of queue theory, and the fluctuation in the passenger arrival rate. Step 2 uses standard simulation methods and Step 3 uses models existing in literature. The methodology is tested in a real sample to show its reliability and accuracy. Then, it is applied to a case study in a busiest airport. The results demonstrate the positive performance of the process considering the trade-off between operational costs and a given service level. Also, a maximum waiting time of thirty minutes is obtained and it is incorporated to the overall service level.

Keywords

Airport logistics; Check-in counter allocation; Optimization models; Queue theory; Simulation.

Resumo

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Esta dissertação trata sobre o problema de alocação de balcões de check-in em um aeroporto. O processo de check-in é um dos serviços aeroportuários mais problemáticos. Ineficiências neste processo propagam problemas como o efeito chicote, sendo uma das causas dos baixos níveis de serviço. Além disso, em geral, as ilhas de check-in ocupam grandes áreas nos aeroportos afetando possíveis receitas de concessão. Uma alocação eficiente de balcões para o processo de check-in poderia reduzir custos aeroportuários e elevar o nível de serviço oferecido para os passageiros. Visando otimizar o ACCAP a nível diário, este trabalho apresenta uma nova metodologia que combina otimização e simulação. O objetivo é determinar o número ótimo, programação e localização de balcões para check-in, de forma a minimizar custos operacionais e garantir um dado nível de serviço. A metodologia proposta divide-se em três passos.

O passo número um faz uso de modelos de otimização para o problema de alocação de balcões de check-in num aeroporto considerando uma política de alocação variável. Dois novos modelos de optimização são apresentados, um para um sistema de check-in comum e outro para um sistema dedicado. Os modelos visam determinar o menor número de balcões por intervalo de tempo e ao mesmo tempo equilibrar os custos operacionais e o nível de serviço oferecido. Estes modelos apresentam dois conjuntos de restrições que levam em consideração aspectos estocásticos do processo de check-in. Um conjunto considera o conceito de fator de utilização da teoria de filas e o outro, a flutuação na taxa de chegada dos passageiros entre intervalos de tempo adjacentes.

O passo número dois usa simulação para avaliar se os resultados do passo anterior cumprem um determinado nível de serviço quando são consideradas incertezas na chegada dos passageiros e tempo de atendimento no processo de check-in. Além disso, a “simulação terminada” ajuda definir a duração adequada do intervalo de tempo e parâmetros chaves relativos aos modelos de otimização.

Em geral, o processo de check-in é analisado considerando um padrão de chegada dos passageiros em procura do serviço de registro e como estes passageiros são atendidos nos balcões. A fim de avaliar essas distribuições: tempo entre chegada dos passageiros e tempo de atendimento, um conjunto de cenários é definido. Os principais cenários para ser testados são para um sistema comum e um dedicado. Assim, testando certo número de replicações para cada experimento de simulação, as estatísticas de desempenho do sistema são obtidas. Estatísticas de interesse tem que ver com o tempo de espera e tamanho da fila.

O passo número três é aplicado só para sistemas de check-in dedicados. Uma vez que se conhece o número de balcões por intervalo de tempo para cada voo é possível minimizar o total de balcões satisfazendo a restrição de adjacência. Esta restrição estipula que todos os balcões do mesmo voo devem estar juntos. Sem a restrição de adjacência, o número mínimo de balcões poderia ser achado facilmente através de uma alocação fixa de recursos por intervalo de tempo. Este procedimento indicaria o número máximo de balcões requeridos (N_{max}) no intervalo de tempo de maior ocupação, mas este resultado não garante uma solução que satisfaz a restrição de adjacência. Assim, os modelos matemáticos relacionados com programação de recursos adjacentes tem que garantir uma alocação ótima de balcões com N_{max} balcões.

A metodologia proposta é testada com um caso de estudo existente na literatura. Primeiro, considerando realidades práticas do planejamento de recursos nos processos aeroportuários, a duração de meia hora identificou-se como o tamanho adequado do intervalo de tempo para a discretização do problema de alocação de balcões de check-in num aeroporto. Depois, comparando os resultados obtidos entre a metodologia e o caso de estudo baseado só em simulação, os resultados demostram a confiabilidade e acurácia da metodologia proposta neste trabalho. Assim, o balance entre custos operacionais e nível de serviço foi alcançado, além de conseguir um tempo máximo de espera de vinte minutos o que representa uma melhora no nível de serviço geral.

A metodologia também é aplicada para um problema relativo ao aeroporto de Guarulhos, São Paulo, Brasil. Este problema é muito mais complexo do que anterior em termos de volume de passageiros e número de voos. O caso de estudo é desenvolvido para um dia especifico e para a principal aliança que opera no aeroporto de Guarulhos. Tomar como referência os resultados de uma análise de qualquer dia é possível para aeroportos de alto fluxo porque eles não apresentam sazonalidade na demanda. Para iniciar o estudo de caso, o problema geral é decomposto em problemas menores considerando distinções naturais como voos domésticos e internacionais ou alianças entre companhias aéreas. Cada grupo obtido representa um cronograma de voos que é avaliado independentemente. Os resultados evidenciam a confiabilidade e acurácia da metodologia para equilibrar custos operacionais e um dado nível de serviço. Respeito a custos operacionais ou factibilidade de implementação, o número de balcões requeridos encaixa na faixa de valores sugeridos pelo procedimento da IATA. Respeito ao nível de serviço, além de cumprir os termos gerais, conseguiu-se um tempo máximo de espera de trinta minutos o que representa uma melhora no nível de serviço geral.

Baseado nos exemplos desenvolvidos neste trabalho e respeito aos modelos de otimização, as restrições que levam em consideração o fator de utilização e o fator de flutuação tem grande impacto nos sistemas de check-in comum. Além disso, o problema de propagação entre dois intervalos de tempo adjacente pode acontecer quando existe um decremento na taxa de chegada dos passageiros. Neste sentido, os modelos de otimização foram reforçados com as restrições de fator de utilização e fator de flutuação para neutralizar esse problema.

Finalmente, ressaltar novamente que a metodologia proposta neste trabalho é baseada em otimização e simulação o que leva em conta um equilíbrio entre custos operacionais e um dado nível de serviço. Ao mesmo tempo busca-se promover a combinação de programação linear e simulação como uma técnica de pesquisa operacional para otimizar processos. Esta nova técnica pode ser facilmente desenvolvida já que otimização e simulação são ferramentas amplamente disponíveis na pesquisa operacional.

Palavras Chaves

Logística aeroportuária; Alocação de balcões de check-in; Modelos de otimização; Teoria de filas; Simulação.

Summary

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1. Introduction

The International Air Transport Association (IATA) press of 12/2013 confirmed the air travel growth in the former years and announced that, for the first time, by the end of 2013, the airline industry carried more than 3 billion passengers. This evolution can be explained thank to the increased competition between airports and airlines, markets liberalization and the development of several low-cost companies (Bruno and Genovese, 2010). The tendency to growth is followed in Brazil, where the air transport sector has been facing high growth rates over the last ten years. Within the next years, air transportation in Brazil is expected to reach the same traffic levels as the ones existing in developed countries. Indeed, air travels are expected to go from 0.3 to 0.7 per person per year, in the medium term (McKinsey and Company, 2010).

In this context of increasing demand for air travel, it is crucial that airport infrastructure grows accordingly. Investments in expansion, modernization, new airports, and even efficient methods for using airport resources may be essential, if one aims to ensure adequate operational capacity and a given level of service. Increasing airport's operational capacity in an environment where competition is fierce, leads airports and airlines to pay attention to cost effectiveness. At the same time, the companies have to deal with increasing service levels requirements and reduce operational costs. Thus, identifying and reducing all superfluous operational processes and underuse equipment is mandatory. With this regard, air transportation business is recurring to new technologies and new logistics practices in order to use the airport resources efficiently.

Logistic practices involved in the flight check-in and the subsequent handling process are key aspects in airports and flights management. Check-in desks are preponderant facilities where the embarking process and the passengers' perception about the airport service level start. Moreover, usually check-in counters occupy a considerable area within the airport affecting airport costs and revenues. In fact, many international airports are already operating in the capacity limits. In others, over dimensioning of counters is preventing the airport to allocate space to profitable activities such as retail areas. Efficiently using the check-in counters may therefore contribute to reduce airport costs and raise the service level offered to customers. An efficient, if not optimal, planning of check-in capacities is therefore required at various levels: at daily level to determine the number of desks and opening and closing hours for the check-in systems, at weekly level to allocate flight and reservations, at monthly level to negotiate contracts with airlines and at yearly level to determine the desk capacity required.

In this context and from the airport management point of view, this work focuses on the Airport Check-in Counter Allocation Problem (ACCAP) at a strategic or tactical level (using a reference day). It proposes a new methodology to determine the optimal check-in system that minimizes operational costs such that a given service level is ensured.

1.1. Motivation

From beginning, the idea was to research in optimization of airport processes. Being in contact with professionals related to the air transportation was mandatory. Thereby, several current needs and evolution tendencies with regard to airport infrastructure management were identified. For example, the need for expanding and rethinking the use of airport infrastructures derives from a growing demand and increasing competitiveness among airlines and airports. In this sense, airlines seek more and more to minimize the area and time they make use of the airport infrastructures in order to reduce operating costs. The airport authorities seek to minimize the areas required for operational purposes so that new spaces can be moved to more profitable activities such as shopping areas. Given the expected expansion of air transportation business in Brazil, the current tendencies mentioned above, and the existence of clearly defined areas that need to be improved, airport logistics is a promising research topic.

This work aims to optimize the ACCAP. For this task, it provides a new methodology to get the optimal check-in system. Despite of the practical relevance of this issue, the ACCAP can be considered a novel problem in the Operational Research literature with an optimization approach (Bruno and Genovese, 2010). Most Operational Research related studies have only resorted to simulation to study the queue characteristics. Moreover, in practical realities, the decision to open or close check-in counters is done on an ad hoc basis by human schedulers, which by far provides efficient solutions (Parlar and Sharafali, 2008).

Thus, developing an analytical tool that optimizes the ACCAP can be seen as a trump card on the airports industry. The results achieved are expected to contribute to reduce airport costs and raise the service level at airports.

1.2. Objectives

The main objective of this work is to provide a methodology for optimizing the Airport Check-in Counter Allocation Problem. It combines optimization and simulation in order to determine the optimal number, schedule and location of check-in desks to open for departing flights, such that operational costs are minimized and a given service level is ensured. Also, the new methodology is to be tested using a real example from the revised literature, and then applied to a real world application concerning to the GRU airport in São Paulo, Brazil.

In addition, the following specific objectives were defined:

- Promote the combination of deterministic and stochastic approaches such as Linear Programming and Simulation as a practical Operational Research tool for optimization.
- Develop mathematical models for the ACCAP that take into account queue and stochastic aspects.

1.3. Methodology: Operational Research tools

This methodology to optimize the ACCAP implies three steps: Step 1, based on optimization models for the ACCAP; Step 2, based on simulation and Step 3, based on an optimization model for the Adjacent Resource Scheduling (ARS). A brief description of each step is given in this section.

First, Step 1 involves optimization models for the ACCAP considering the variable desk allocation policy. This approach is based on the proposal of Bruno and Genovese (2010), with modifications. It is presented two new optimization models, one for a common check-in system and the other for a dedicated check-in system. They aim to determine the minimum number of check-in desks to be opened by time interval, such that operational costs and the quality of service are balanced. These models present two set of constraints in order to take into account queue and stochastic aspects. One considers the utilization factor concept of queue theory, and the other, the fluctuation in the passenger arrival rate. This step is a deterministic scheduling problem based on the departure flights schedule, reference arrival pattern and a rough check-in time.

Second, Step 2 recurs to simulation in order to assess if the results reached through Step 1 meet a given service level in terms of queue system characteristics when considering real uncertainty behaviour of check-in processes. Furthermore, “terminating simulation” helps to define the proper length of the time interval and key parameters concerning to the optimization models. In overall, the airport check-in process is studied considering a passenger arrival pattern for check-in service and how the passengers are served at the counters. In order to scrutinize both distributions, passenger arrival and check-in service, a set of scenarios are defined. The main scenarios to be tested are the common and dedicated check-in systems. Thus, testing a set of replications for the same initial conditions and sampling passenger arrival and check-in service distributions, the system’s statistical performance is obtained.

Third, Step 3 focuses only on the dedicated check-in systems. Once one has determined the required number of desks by time interval for each flight, it is possible to minimize the total number of desks under the adjacent constraint. This constraint stipulates that all desks for the same flight should be adjacent. Without the adjacency constraint, the minimal number of desks could be found easily by the Earliest Release Date First rule (Fixed Interval Scheduling). This would indicate the number of required desks (N_{max}) at the busiest time interval but it would not guarantee an optimal solution satisfying the adjacency constraint. Thus, mathematical models related with the ARS have to guarantee an optimal desk allocation with N_{max} desks. This step is a deterministic scheduling problem based on a given required number of desks for each flight by time interval.

1.4. Work Structure

This work is structured as follows. Chapter 2 discusses related literature and provides an insight on the ACCAP terminology. Additionally, based on IATA-ADRM (2004), the service level related to check-in process and a procedure to manage the ACCAP are provided. Chapter 3 presents the Operational Research tools involved in the methodology: the two optimization models to solve the ACCAP (one for common and the other for dedicated check-in systems), the simulation features and an optimization model for ARS. Also, the proposed methodology is applied to a sample test obtained from the revised literature. The purpose of this test is to learn the work procedure of the methodology and to prove his reliability and accuracy. Chapter 4 presents a case study where the proposed methodology is applied to a real world problem concerning the GRU airport in São Paulo, Brazil. Finally, Chapter 5 derives the conclusions of this work and future directions of research.

2. Literature review

Despite the practical relevance of the Airport Check-in Counter Allocation Problem, it can be considered a novel problem in Operational Research literature with an optimization approach (Bruno and Genovese, 2010). It can be explained because most of the Operational Research related studies have only resorted to simulation to study the queue characteristics. In this section, it is only cited the works which served as reference for the most of studies related to ACCAP. Chun and Mak (1999) introduced an Intelligent Resource Simulation System (IRSS) to predict on a daily basis how many check-in counters should be allocated to each departure flight while providing passengers with a given quality of service. The major contribution of their work relies on the number of factors considered: 1) different services rates for different destinations and airlines; 2) different passenger arrival rates for different times of the day or days of the week; and 3) different requirements for different service levels. Following this approach, Krug (2002) used the combination of simulation and various search procedures, such as a greedy or gradient search method, to optimize the resource allocation problem. However, this approach did not include an optimization technique.

A first attempt to solve a similar problem with Linear Programming approach has been provided by Atkins et al. (2003). They employed simulation (stochastic) and Integer programming (deterministic) tools to improve passenger flows and customer service at Vancouver International Airport. Simulation was employed to meet the service criterion and it was run until the minimum staffing level met the defined service level. Linear Programming was used to determine the shift schedules with a minimum number of staff hours that satisfied the airport-wide staffing requirements on a daily basis.

An important approach of check-in desk assignment problem has also been addressed by Yan et al. (2004). They studied a deterministic scheduling problem with a different assignment problem. The objective was to determine an assignment on a monthly basis such that the total passenger walking distance was minimized combined with a constraint of allowable inconsistency. A flight assignment was considered consistent when the same flight number was assigned to the same block of desks on different days. Given the problem's size and complexity, the authors had to resort to a heuristic method to solve the model.

Based on the work of Atkins et al. (2003), Van Dijk and Van der Sluis (2006) deepen the check-in problem by proposing an integrated stochastic (simulation) and deterministic (mathematical programming) approach. First, simulation was used to determine minimal numbers of desks in order to meet a service level for each separate flight. Next, integer-programming formulations were provided to minimize the total number of desks under the realistic constraint that the desks for the same flight should be adjacent. According to these authors, simulation and mathematical programming tools are widely available, but the combination of them can be regarded as an illustration of a new practical Operational Research tool for optimization.

Parlar and Sharafali (2008) provide a dynamic allocation of airline check-in counters. First, considering a dedicated system, they propose a multicounter queue model based on the time-dependent operating characteristics to the queue process. Then, they formulate a stochastic dynamic programming model to determine the optimal numbers of counters to open over a time window. To the best of my knowledge, that work is the first to consider the optimization of check-in counter systems based on cost, as up to that moment, most studies considered only the service-level approach. Finally, Bruno and Genovese (2010) propose new optimization models for the ACCAP. They decide the optimal number of desks to open for departing flights, such that the operative costs and passenger waiting time at the terminal are balanced.

In this work, the use of optimization models to solve the ACCAP is further extended. Specifically, and based on the work of Bruno and Genovese (2010), two new optimization models for common and dedicated systems are formulated. These models present two set of constraints to take into account queue and stochastic aspects. One considers the utilization factor concept of queue theory; the other, the fluctuation in the passenger arrival rate. It is important to highlight that these model are part of the methodology which combines optimization and simulation. In this way, the general goal is to determine the optimal number, schedule and location of check-in desks to open for departing flights, such that operational costs are minimized and a given service level is ensured.

2.1. The check-in process and related terminology

The check-in process is one of the services provided by airports. It naturally emerges from the need for accommodating passengers in flight cabins and loading their baggage. As a general process, the inputs are the duality passenger-baggage; and the outputs are the passengers with their boarding card and their luggage carried to the airplane (Diaz, 2008). Also, given quality of service is defined in order to satisfy customers' needs and obtain the maximum profit with the minimum cost.

Passengers have at their disposal several ways to fulfill check-in. In general, they can be grouped on two main categories: "Traditional check-in" and "Self check-in". The former is the usual option where the all check-in process is taken care at counters. The latter is currently developing considerably benefiting from technology advances. At the moment, the most common options are:

- Auto check-in or quick check-in: it makes use of kiosks where passengers insert their information and get their boarding cards by themselves. Still, it requires special counters to leave the baggage, or in some airports, these counters are shared with the traditional check-in passengers.
- Online check-in: passengers print their boarding cards at home. Regarding to the luggage, it is the same situation to auto check-in.
- Check-in by mobile-phone: the same as online check-in, except that it is performed in a mobile-phone.

The terminology used in practice to describe the features of an airport check-in process can vary among authors. With this regard, a well-accepted reference guide regarding the air transport concepts is the one provided by IATA-ADRM (2004). Then, it is assumed the following standard definitions:

- Arrival pattern: represents the proportion of passengers' arrival for check-in service distributed by fixed time intervals. Table 1 exemplifies a reference arrival pattern.

- Check-in period: period before flight departure during which passengers are allowed to register for the flight. It starts at Flight-open time and ends at Flight close-out time, after which the flight is said to be closed and no more passengers are allowed to check-in.
- Departure flight schedule: information indicating the number of departure flights, the number of passengers and the starting time interval for each flight. Table 2 represents an example of a departure flight schedule based upon a flight realization at the Dutch Airport Schiphol.

Table 1 - Reference Arrival Pattern

Time intervals over the check-in period	% of passengers
210 min - 180 min	*5*
180 min - 150 min	*10*
150 min - 120 min	*20*
120 min - 90 min	*30*
90 min - 60 min	*20*
60 min - 30 min	*15*
30 min - 0 min	*0*

Source: Van Dijk and Van der Sluis (2006)

Table 2 - Departure Flight Schedule

Flight	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Number of passengers	*150*	*210*	*240*	*180*	*270*	*150*	*210*	*300*	*180*	*270*
Starting period	*1*	*2*	*3*	*3*	*4*	*5*	*6*	*7*	*7*	*8*

Source: Van Dijk and Van der Sluis (2006)

- Common check-in system: passengers can check-in for their flights at any available desk during the check-in period.
- Dedicated check-in system: passengers have to check-in at specific position desks during the check-in period.
- Constant desk allocation policy (static): each flight is allocated to a constant number of desks during its entire check-in period.
- Variable desk allocation policy (dynamic): each flight is allocated to a variable number of desks during its check-in period.
- Service level: customer satisfaction in terms of waiting time or queue size, specially. IATA-ADRM (2004) is a good source for getting this information. Furthermore, there are interesting works in order to know the users'

perception about comfort for specific airports and areas inside them. For example, regarding to GRU airport, Correia et al. (2008) present a composite measure of the airport service level, as a function of individual components (service level of areas). Similarly, Falcão et al. (2012) provide a methodology to establish the service level for specifics areas at some airports of Brazil.

- Common queue configuration: one queue for all the counters assigned to a flight or groups of flights.
- Single queue configuration: a queue for each counter.
- Originating passenger: passenger taking the first flight of the trip.
- Passenger on transfer: passenger arriving at the airport from a previous flight to take a connecting flight. This kind of passenger can do or not the check-in process in the stopover, depending on the characteristics of the trip.

2.2. Service level for the airport check-in process

In this section, some IATA-ADRM (2004) suggestions regarding to the service level for airport check-in process are exposed. The service level could be considered as a range of values about the supply ability to meet the demand, and it can combine quantitative and qualitative measures. In this way, IATA defines ranges of service level measures from A to F, as given in Table 3. It should be noted that the service level C is considered the "required bottom line" for design objectives, since it denotes a good service at a reasonable cost (Diaz, 2008).

Table 3 - Ranges of service level measures according to IATA

Level	Quality of service	Passengers flows	Delays	Comfort	System
A	*EXCELLENT*	*Free-Flow*	*No*	*Excellent*	*Ok*
B	*HIGH*	*Stable*	*Very Few*	*High*	*Ok*
C	***GOOD***	***Stable***	***Acceptable***	***Good***	***Ok***
D	*ADEQUATE*	*Unstable*	*Acceptable*	*Adequate*	*Ok*
E	*INADEQUATE*	*Unstable*	*Unacceptable*	*Inadequate*	*Ok*
F	*UNACCEPTABLE*	*Cross-flows*	*Unacceptable*	*Unacceptable*	*Breakdown*

Source: IATA – ADRM (2004)

2.2.1. Check-in queue area

It is possible to place the check-in counter using either linear or island layouts. For these two types of check-in configuration, the size recommended by IATA can be seen in Figures 1 and 2. With regard to the passenger space in queue, IATA suggests four different sets of space at the check-in area. Table 4 provides the characteristics or parameters for each set.

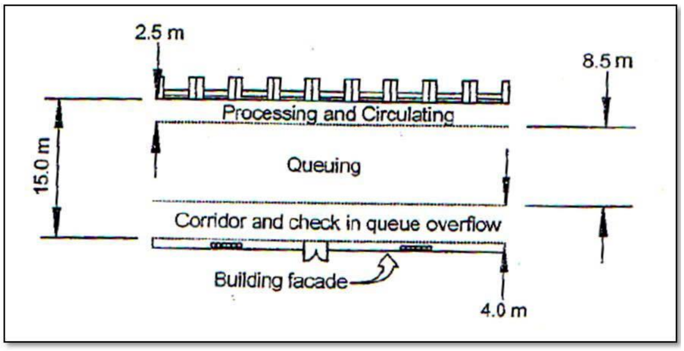


Figure 1 - Check-in Frontal type with a Maximum Queuing Time of 30-35 Minutes
Source: IATA – ADRM (2004)

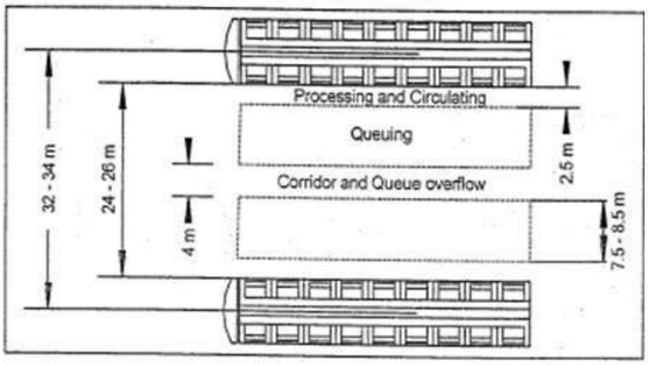


Figure 2 - Check-in Island type with a Maximum Queuing Time of 30-35 Minutes
Source: IATA – ADRM (2004)

Table 4 - Level of Service Space Standards (m^2/occupant) at check-in for a single queue

	A	B	C	D	E
1. Few carts and few passengers with check-in luggage (row width 1.2m)	*1.7*	*1.4*	*1.2*	*1.1*	*0.9*
2. Few carts and 1 or 2 pieces of luggage per passenger (row width 1.2m)	*1.8*	*1.5*	*1.3*	*1.2*	*1.1*
3. High percentage of passengers using carts (row width 1.4m)	*2.3*	*1.9*	*1.7*	*1.6*	*1.5*
4. "Heavy" flights with 2 or more items per passenger and a high percentage of passenger using carts (row width 1.4m)	*2.6*	*2.3*	*2.0*	*1.9*	*1.8*

Source: IATA – ADRM (2004)

For this work, the service level in terms of queue size must ensure that 90% of all passengers to stay inside the check-in area (Van Dijk and Van der Sluis, 2006). Based on Table 4, an area of 1.2 meters of width and 1.4 of length is established as an acceptable waiting area for a passenger. That width matches with the standard size of a single check-in counter (IATA-ADRM, 2004). Then, considering the length of the waiting area of 8.5 meters (see Figure 1), at most 6 people can wait in front of each check-in desk.

2.2.2. Check-in queuing time

The waiting time is a significant factor in determining the quality of service and must be considered as a prime variable to measure the service level. With this regard, IATA establishes a reference for queuing times such shown in Table 5.

Table 5 - Maximum Waiting Time Guidelines in minutes

	Short to acceptable	**Acceptable to long**
Check-in Economy	*0 – 12*	*12 – 35*
Check-in Business Class	*0 – 3*	*3 – 5*

Source: IATA – ADRM (2004)

For this work and regarding to waiting time, at least 90% of all passengers reach their check-in desk within 10 minutes and no passenger waits more than 35 minutes (Van Dijk and Van der Sluis, 2006).

Section 2.3 introduces the methodology proposed by IATA for airport check-in counter allocation problem. It is followed by most of the airports around the world regarding to the check-in counters management.

2.3. Check-in counter allocation – IATA suggestion

IATA-ADRM (2004) suggests a procedure to determine the required number of desks for a specific departure flight schedule. The following rule determines the requirements for common and dedicated check-in systems:

- Step A: Calculate the peak 30-minutes demand for check-in service.
- Step B: Determine the intermediate result using parameters provided by IATA by means of tables and graphics.
- Step C: Calculate the number of economy class desks in common system.
- Step D: Calculate the total number of check-in counters (economy + business).
- Step E: Make adjustment for dedicated facilities.

This procedure is better understood through an example. For the effect, it will be used the arrival pattern of Table 1, the departure flight schedule of Table 2 and a check-in period of three hours. The departure flight schedule used assumes that flights with more than 210 passengers are considered long haul international flights, while the others are considered short haul international flights. In this example, there are no domestic flights. Two cases are presented, one considering time intervals of one hour (CASE I), and the other considering time intervals of 30 minutes (CASE II). Next, additional parameters and assumptions are detailed:

- Arrival distribution: Table 6 and Table 7 show the demand by interval within the check-in period of each flight for CASE I and CASE II, respectively.
- Desk service time: equals to 2 minutes/passenger as in Van Dijk and Van der Sluis (2006).
- It is considered that there was not transfer passengers. In other words, all the passengers embarked in every flight were checked-in at the counters.

Table 6 - Arrival distribution for CASE I

Flight || time interval	1	2	3	4	5	6	7	8	9	10
1	*53*	*75*	*22*							
2		*74*	*105*	*31*						
3			*84*	*120*	*36*					
4			*63*	*90*	*27*					
5				*95*	*135*	*40*				
6					*53*	*75*	*22*			
7						*74*	*105*	*31*		
8							*105*	*150*	*45*	
9							*63*	*90*	*27*	
10								*95*	*135*	*40*
Passengers	*53*	*149*	*274*	*336*	*251*	*189*	*295*	*366*	*207*	*40*

Table 7 - Arrival distribution for CASE II

F || t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	*23*	*30*	*45*	*30*	*22*															
2			*32*	*42*	*63*	*42*	*31*													
3					*36*	*48*	*72*	*48*	*36*											
4					*27*	*36*	*54*	*36*	*27*											
5							*41*	*54*	*81*	*54*	*40*									
6									*23*	*30*	*45*	*30*	*22*							
7											*32*	*42*	*63*	*42*	*31*					
8													*45*	*60*	*90*	*60*	*45*			
9													*27*	*36*	*54*	*36*	*27*			
10															*41*	*54*	*81*	*54*	*40*	
Passengers	*23*	*30*	*77*	*72*	*148*	*126*	*198*	*138*	*167*	*84*	*117*	*72*	*157*	*138*	*216*	*150*	*153*	*54*	*40*	*0*

Sections 2.3.1 and 2.3.2 present the results obtained using IATA procedure. The objective is to clarify how the procedure works, and simultaneously to show why 30 minutes time intervals are preferable to one-hour time intervals.

2.3.1. CASE I

a) Step A calculates the peak 30-minutes demand for check-in service. In situations as the CASE I (time intervals of one hour), equation (1) is recommended since the information of the peak 30-minutes is not available.

$$X = (PHP\ economy\ class)(F1)(F2) \tag{1}$$

Where:

X = Peak 30-minutes demand for check-in service.

PHP = Peak hour originating economy class passengers.

F1 = % of the PHP in the peak 30-minutes from Table 8.

F2 = Additional demand generated by the flights departing before and after the peak hour period from Table 9.

Table 8 - F1: Peak 30-min. demand for check-in service as a percentage of PHP

Number of flight during the peak hour period	Domestic/Short Haul International Flight	Long Haul International Flight
1	*39%*	*29%*
2	*36%*	*28%*
3	*33%*	*26%*
4 or more	*30%*	*25%*

Source: IATA – ADRM (2004)

Table 9 - F2: Additional demand generated by the flights departing before and after PHP

Average passenger load in the hour before and after the peak hour period in % of the PHP	Domestic	Short Haul International Flight	Long Haul International Flight
90%	*1.37*	*1.43*	*1.62*
80%	*1.31*	*1.40*	*1.54*
70%	*1.26*	*1.35*	*1.47*
60%	*1.22*	*1.30*	*1.40*
50%	*1.18*	*1.25*	*1.33*
40%	*1.14*	*1.20*	*1.26*
30%	*1.11*	*1.15*	*1.19*
20%	*1.07*	*1.10*	*1.12*
10%	*1.03*	*1.06*	*1.06*

Source: IATA – ADRM (2004)

Based on Table 6, the peak period occurred in the 8th time interval. During that time interval there are 4 flights (7, 8, 9 and 10, two short haul and two long haul flights) and 366 passengers. Assuming that 10% of passengers are business-class (Diaz, 2008), the PHP would be 330 passengers. Also, from Table 6, the time intervals before and after the peak period present 266 and 187 economy-class passengers, respectively. Those numbers represent the 80.6% and 56.7% of the PHP. Then, the average passenger load in the hour before and after the peak hour in percentage of PHP will be 68.65 or 69%.

The value of F1 is obtained from Table 8. Considering the number of flights during the peak hour and the proportion of each type of flight, F1 would be:

$$F1 = \left(\frac{1}{2} \times 30\%\right) + \left(\frac{1}{2} \times 25\%\right) = 27.5\% \qquad (2)$$

In the same way than F1, the value of F2 is obtained from Table 9. But before, it is necessary to perform an interpolation such shown in Table 10.

Table 10 - Average passenger load of 69% of the PHP

Average passenger load in the hour before and after the peak hour period in % of the PHP	Short Haul International Flight	Long Haul International Flight
60	*1.3*	*1.4*
69	*1.345*	*1.463*
70	*1.35*	*1.47*

$$F2 = \left(\frac{1}{2} \times 1.345\right) + \left(\frac{1}{2} \times 1.463\right) = 1.404 \quad (3)$$

So the peak 30-minutes demand for check-in service results:

$$X = (330)(0.275)(1.404) = 127.4 = 128\, passengers \quad (4)$$

b) Step B determines the intermediate result (S). With the value of Peak 30-minutes demand computed previously and using the Maximum Queuing Time (MQT) chart shown in Figure 3, the values of S are obtained. Two values are presented (Table 11), one considering MQT of 30 minutes and the other considering MQT of 10 minutes. These two values establish a range of desks.

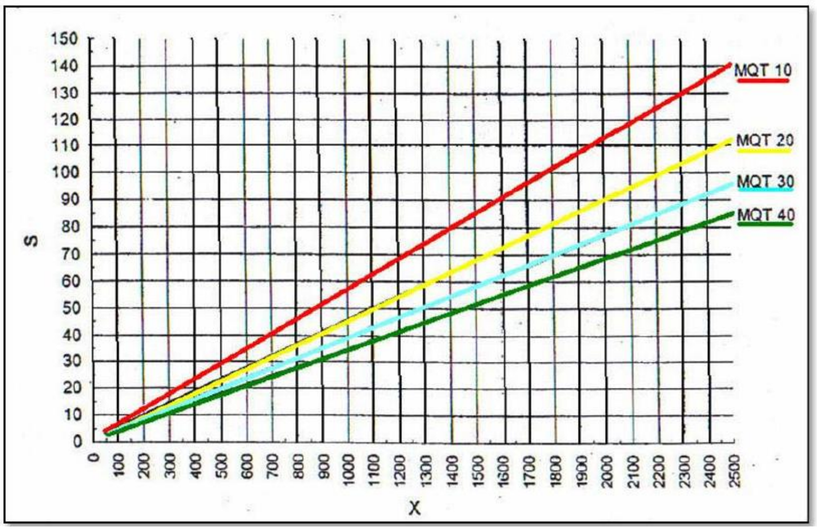


Figure 3 - Maximum Queuing Time (MQT) chart
Source: IATA – ADRM (2004)

Where:

X = Peak 30-minutes demand for the check-in service.

S = Intermediate result.

MQT = Maximum Queuing time (minutes).

Table 11 - Intermediate results for MQT of 30 and 10 minutes

Maximum Queuing Time	Intermediate result
30 minutes	*6*
10 minutes	*8*

c) Step C calculates the number of economy-class counters for common systems. Considering the former results, an average check-in time of 120 seconds and the Equation (5); the number of counters is obtained and shown in Table 12.

$$CE = (S)(PT\ /\ 120) \tag{5}$$

Where:

CE = Number of economy check-in servers assuming common use.

PT = Average processing time at check-in servers in seconds.

Table 12 - Economy check-in counters for MQT of 30 and 10 minutes

Maximum Queuing Time	Economy check-in counters
30 minutes	*6*
10 minutes	*8*

d) Step D calculates the total number of counters (economy plus business class) for common systems. It is estimated that 20% of desks must be designated to business class (Diaz, 2008). Considering this factor over the former results, the number of desks for common systems is obtained and shown in Table 13.

Table 13 - Total number of check-in counters assuming common use

Maximum Queuing Time	Total check-in counters
30 minutes	*8*
10 minutes	*10*

e) Step E makes adjustment for dedicated check-in systems. Experience shows that the total number of check-in positions in common use should be increased by 30 to 40% for dedicated facilities (Diaz, 2008). In this way, an increase of 35% is considered and the results for this step are shown in Table 14.

Table 14 - Total number of check-in counters assuming dedicated system for CASE I

Maximum Queuing Time	Total check-in counters
30 minutes	*11*
10 minutes	*14*

2.3.2. CASE II

For this case, the Step A only requires to identify the busiest time interval of Table 7 and consider that 10% of passengers are business class (Diaz, 2008). Thus, the peak 30-minutes demand of economy class (X) would be 195. Next, the development from Step B to Step E is the same followed in CASE I. Finally, the result for CASE II considering a dedicated system is shown in Table 15.

Table 15 - Total number of check-in counters assuming dedicated system for CASE II

Maximum Queuing Time	Total check-in counters
30 minutes	*14*
10 minutes	*16*

The examples developed in Section 2.3.1 and 2.3.2 take into account the same input data used in a case study carried out by Van Dijk and Van der Sluis (2006). These authors used simulation and linear programming and assume hourly time intervals to determine that 15 check-in counters are necessary in a dedicated check-in system. Alternatively, for the same problem and using half-an-hour time intervals, the IATA procedure indicates 16 desks. Thus, these results foresee that the half an hour represents a right length of time interval to ACCAP. At the same time, the reliability of the IATA recommendation is proved. Since the IATA procedure provides the total number of required check-in counters, it is applicable mainly for tactical and strategic planning, but not for operational purposes, as no information per time interval is given. In the same way, the next chapter provides a methodology for the ACCAP to be used at a strategic or a tactical level. For the former, it uses a reference day for each instance of the cycle. For the latter, the most congested day as reference. Additionally, the proposed methodology could be useful at a daily procedure because it provides not only the number of desks, but also the opening and closing hours of counters throughout the time window.

3. New methodology to optimize the ACCAP

This chapter exposes the new methodology to optimize the ACCAP. First, Section 3.1 presents the mathematical models for the ACCAP. Second. Section 3.2 provides simulation concepts relevant for this work. Third, Section 3.3 explains the adjacent resource scheduling theory. Fourth, Section 3.4 details the work procedure that enables the integration of the three Steps of the methodology. Finally, Section 3.5 describes a sample test to clarify the whole methodology.

3.1. Step 1: Mathematical models for the Airport Check-in Counter Allocation Problem (ACCAP)

From a corporate point of view, the most common objective is the minimization of resource costs while ensuring a given service level. With regard to airport check-in desks management, this objective can be translated into the determination of the minimum number of desks to be opened that ensures the service coverage. The number of desks opened per flight can be determined based on a constant or a variable policy. The former establishes a constant number of desks to be open during all check-in period. The latter varies the number of desks opened per time interval in accordance to passengers' affluence. Thus, in a variable policy, peak time intervals will have more desks while off-peak will have less and that will lead, in principle, to a more optimized solution (Chun and Mak, 1999). This work will therefore focus on the variable desk allocation policy.

The ACCAP will be approached considering the two check-in systems, the common and the dedicated. The ACCAP model regarding to the common system will from now on be designated as CACCAP. The DACCAP acronym designates the dedicated system. While the CACCAP model gives the total number of desks per time interval, the DACCAP model gives the number of check-in desks per time interval and per flight. Both models can be classified as pure deterministic scheduling models as the departure flight schedule, passenger arrival pattern and a rough check-in time are known in advance. Both models are based on the following hypothesis:

- Discrete time window: The time horizon *T* is divided in intervals with constant width. All parameters and variables are referred to each interval. On this basis, the problem becomes a discrete problem.
- Arrival distribution: The uncertainty in passenger behavior does not allow forecasting the exact distribution of arrivals to each desk within the check-in period. But, in order to simplify this issue, it is possible to analyze historical data and defining an specific arrival pattern.
- Desk service time (check-in time): It represents the time needed to process and accept a passenger. This capacity can be assumed equal for each desk, and the value can be calculated based on the real check-in processes analyses.
- Desk opening cost: It represents the operational expenses for the airport administration to have a check-in desk for assignment to departure flights.

Section 3.1.1 provides the notation for the mathematical models. Next, the CACCAP and DACCAP models are presented, respectively, in Section 3.1.2 and Section 3.1.3.

3.1.1. Notation

The models use the following sets and parameters:

- *T*: time window (a day or some hours of a day);
- *l*: length of the considered time interval;
- *t*: representative index of the single time interval;
- *j*: representative index of the single flight;
- *M*: set of time intervals in *T* or the number of time intervals in *T* ($M = T/l$);
- *J*: set of flights scheduled in *T*;
- p_j: desk service time for flight *j*;
- *k*: average desk service time for the departure flight schedule;
- $d_{j,t}$: service demand from passengers of flight *j* at time interval *t*;
- $I0_{jt}$: number of passengers of flight *j* waiting before desk opening;
- S_t: cost associated with an available check-in desk at time interval *t*;
- H_j: cost associated with the passenger in queue related to the flight *j*;

- $A_{j,t}$: *J*x*M* matrix; the coefficient $a_{j,t}$ is equal to 1 at time interval when passengers of flight j cannot check-in and when it is not possible for the passengers to check-in during the next time interval (case of the last opened time interval for each flight); and 0 in all other time intervals;
- *c*: available time for check-in process by a desk within the time interval *t*;
- α: maximum percentage of passengers in a queue at the end of time interval *t*;
- U_t: utilization factor at time interval *t*;
- F_t: passenger fluctuation factor at time interval *t*;

Furthermore, the model considers three sets of decision variables:

- $q_{j,t}$: number of passengers of flight j to be accepted during time interval t;
- B_t: number of desks to be assigned during each time interval t;
- $I_{j,t}$: number of passengers in a queue for flight j at the end of time interval t.

3.1.2. Integer programming formulation for CACCAP

The CACCAP model can be formulated as follows:

$$Min\ Z = \sum_J \sum_M \left(H_j I_{jt} + S_t B_t\right) \qquad (3.1)$$

S.t.

$$I_{jt} = I_{j(t-1)} + d_{jt} - q_{jt} \qquad \forall j \in J,\ \forall t \in M \qquad (3.2)$$

$$\sum_{\boldsymbol{J}} p_{\boldsymbol{j}} q_{jt} \le cB_t \qquad \forall t \in M \qquad (3.3)$$

$$A_{\boldsymbol{jt}} I_{jt} = 0 \qquad \forall j \in J,\ \forall t \in M \qquad (3.4)$$

$$\sum_{\boldsymbol{J}} I_{\boldsymbol{jt}} \le \alpha\left(\sum_J d_{jt} + \sum_J I0_{jt}\right) \qquad \forall t \in M \qquad (3.5)$$

$$\frac{\left(\sum_{j=1}^{J} d_{jt} + \sum_{j=1}^{J} I0_{jt}\right)}{(l\,U_t)} \le (B_t / k) \qquad \forall t \in M \qquad (3.6)$$

$$B_t \ge F_t B_{(t-1)} \qquad \forall t \in M \qquad (3.7)$$

$$q_{jt}\ ,\ I_{jt}\ ,B_t\ \geq 0 \qquad \forall\, j\ \in J\ ,\ \forall\, t\ \in M \qquad (3.8)$$

$$B_t \in N \qquad \forall\, t\ \in M \qquad (3.9)$$

The objective function (3.1) minimizes the total cost given as the sum of two components: the costs associated with passengers in queue and the costs associated with opening a desk. Constraints (3.2) keep track of passengers in the queue for each flight during each time interval. The number of passengers in a queue for flight j at the end of an interval t is the sum of passengers in queue for flight j from the previous interval plus the passengers of flight j arriving for check-in service at t minus the number of passengers that completed the check-in process at this time interval t. Constraints (3.3) represent capacity constraints by ensuring that the total number of passengers served during interval t does not exceed the time capacity available given the number of desks assigned. Constraints (3.4) express the fact that all passengers of flight j must be accepted within the check-in period. Constraints (3.5) represent a given service level by not allowing more than α percent of the passengers that arrived in interval t to be postponed to interval $t + 1$. Constraints (3.6) represent the utilization factor concept for service facilities (check-in counters) concerning to queue theory. This factor represents the fraction of the system's service capacity that is being utilized on the average by arriving customers (Hillier and Lieberman, 2013). As an overview and for any queue system, the utilization factor has to be less than one in order to reach the steady-state condition. Constraints (3.7) take into account the changes in the passenger arrival rate between two adjacent time intervals. Since the arrival pattern is defined as parameter, another way to control the impact of passenger fluctuation is to focus in the desk number relationship between two adjacent time intervals. The fluctuation factor represents this relationship. Section 3.4 explains how to value the utilization and fluctuation factors (UFF) per time interval for a specific case study. Finally, constraints (3.8) and (3.9) define the domain of decision variables.

It is worthy to mention that if we replace $d_{j,t}$ with $D_{j,t}$ and $q_{j,t}$ with $Q_{j,t}$, we can interpret $D_{j,t}$ as the external demand for an item j at time t and $Q_{j,t}$ as the production quantity for item j at time t. Thus, the model (3.1)-(3.9) becomes perfectly equivalent to a common formulation of the well-known Multi-item Capacitated Lot Sizing Problem, which is known to be NP-hard when capacity is not constant (Pochet and Wolsey, 2006).

3.1.3. Integer programming formulation for DACCAP

The DACCAP model differs from the CACCAP model since each open check-in desk is allocated specifically to one flight during each interval t. Thus, the DACCAP model suffered some minor changes with regard to the CACCAP. Let us consider the additional set of decision variables $Desk_{j,t}$ that represent the number of opened check-in desks for flight j during each interval t. Also, the utilization and fluctuation factors are defined for each flight and for each interval such as U_{jt} and F_{jt}. Then, the DACCAP model can be formulated as follows:

$$Min\ W = \sum_j \sum_M \left(H_j I_{jt} + S_t Desk_{jt} \right) \tag{3.10}$$

S.t. (3.2), (3.4), (3.8)

$$p_j q_{jt} \leq c Desk_{jt} \qquad \forall j \in J,\ \forall t \in M \tag{3.11}$$

$$I_{jt} \leq \alpha(d_{jt} + I0_{jt}) \qquad \forall j \in J,\ \forall t \in M \tag{3.12}$$

$$\frac{(d_{jt} + I0_{jt})}{(l\, U_{jt})} \leq (Desk_{jt}/p_j) \qquad \forall j \in J,\ \forall t \in M \tag{3.13}$$

$$Desk_{jt} \geq F_{jt} Desk_{j(t-1)} \qquad \forall j \in J,\ \forall t \in M \tag{3.14}$$

$$Desk_{jt} \in N \qquad \forall j \in J,\ \forall t \in M \tag{3.15}$$

The objective function (3.10) has the same meaning of equation (3.1). It minimizes the total cost given as the sum of passengers in queue costs plus the costs associated with opening a desk. Constraints (3.11) represent capacity constraints for each flight per time interval. Constraints (3.12) express a given service level for the dedicated check-in system. Basically, for each flight, these constraints limit the number of people that arrive during a time interval t and that will process their check-in only during interval $t + 1$. Constraints (3.13) represent the utilization factor concept for the service facilities (check-in counters) concerning to queue theory. Constraints (3.14) take into account the changes in the passenger arrival rate between two adjacent time intervals. The explanation about constraints (3.13) and (3.14) is the same regarding to the CACCAP model. Finally, constraints (3.15) define the domain of decision variables.

3.2. Step 2: Simulation

According to Joustra and Van Dijk (2001), a pure deterministic approach (such as optimization models) ignores stochastic aspects that are intrinsically involved in the check-in process such as passenger arrival times and check-in times. So, they argue the importance of simulation in order to capture the non-steady behaviour of the check-in process. Also, they stand out the ease of simulation tools for testing different parameters such as size of time intervals, arrival patterns and check-in times; and alternative operational check-in rules such as common or dedicated check-in systems.

As an overview and based on simulation, the check-in process is studied taking into account the passengers demand for the check-in service and how the passengers are served at counters. In order to scrutinize both distributions: passenger arrival and service time at counters, a set of scenarios is defined. The main scenarios to be tested are the common and dedicated check-in systems. When the simulation model is confirmed (see Figure 4 that shows the model in Arena Software for the airport check-in process), testing a number of replications for the same initial conditions and sampling passenger arrival and service time distributions, it is possible to obtain the performance of the system described statistically (Chun and Mak, 1999). Statistics of interest have to do with waiting time and queue size. Furthermore, Joustra and Van Dijk (2001) highlight the use of terminating simulation in order to analyze the transient periods or successive variations throughout the time window. This would allow assessing the service level not only in the whole time window, but during each time interval, too.

The simulation software used in this work is ARENA. It is a computer package for discrete event simulation from Rockwell Corporation. According to Prado (2010), this software allows the user to create a visual model of a system by drawing simulation objects (modules) directly on the screen (graphical user interface). This flexibility allows these modules to simulate almost any process.

In this work, simulation is used to test service levels in a process and at same time, prevent under or over-utilization of resources. With this purpose, Maria (1997) proposes a guideline in order to develop a right simulation project, which was used as a reference for this work. Section 3.2.1 covers some simulation concepts relevant for this work.

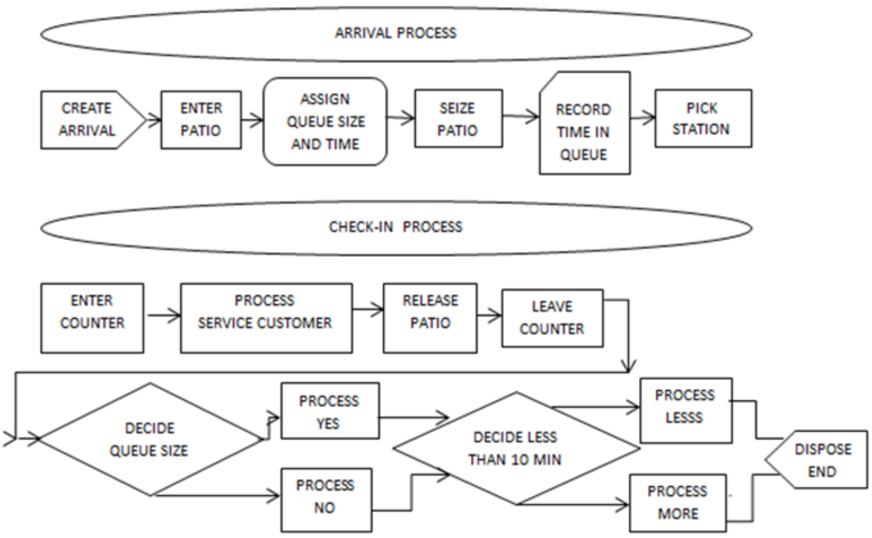


Figure 4 – Airport check-in process model in Arena software

3.2.1. Basic concepts of simulation

This section details some basic simulation concepts useful for this work.

- Type of simulation: The two main types of simulation are Terminating Simulation and Non-terminating Simulation. The former starts at a defined state or time and ends when it reaches some other defined state or time. The latter focuses on the steady-state behavior of the system. Joustra and Van Dijk (2001) stand out the use of terminating simulation in airport check-in process because it works with a finite size of "calling population" within the check-in period. Furthermore, they stand out that terminating simulation does not intend to measure the steady-state behavior of a system and the average measures are of little meaning. On the other hand, since terminating simulation contains transient periods, the meaningful information is reported by the successive fluctuation in the whole time window.
- Warm-up period: Initially there is a simulation start-up phase. This phase allows the model to reach a certain steady state (Bevilacqua, 2010). A practical procedure considered for this work is briefly explained as follows:

  - First, run the ACCAP model without the UFF constraints (equation 3.6 and 3.7 for a common system and equation 3.13 and 3.14 for a dedicated system), and then calculate the required number of check-in desks.

  - With the outcome of the first step and based on queue theory, get the average waiting time and queue size during each time interval. Then, taking into account the number of passengers by time interval, obtain the weighted average of these queue features for the total system. These values and the population size are the reference for the next steps.

  - As suggestion for the warm-up period, test periods multiple of the time interval length and choose an arrival rate that does not generate queue at the end of the warm-up period.

  - Perform each simulation experiment considering several replications.

  - Each scenario provides average queue results which are contrasted with the reference. Thus, the stage more nearby to the reference will suggest the proper length of the warm-up period.

- Set of results: Two sets of results are possible to obtain: at the end of a run and at the end of a trial (Prado, 2010). The former provides relevant values over a run. The latter provides a result summary based on several runs. Each run is characterized with a proper set of random numbers called “Random Sampling” and every random sampling yields a different set of results.
- Time between arrivals: Statistical distributions model the inter-arrival time (Hillier and Lieberman, 2013). For example, the exponential distribution is often used in the literature to characterize the passenger arrival. For that distribution, to calculate the time between arrivals, it is necessary to know how many passengers arrive by interval and the interval length. So, if over X minutes, Y passengers arrive, one passenger is envisaged to arrive every Z minute. In formula, it is as follows:

$$Z = \frac{X}{Y} = \frac{1}{\lambda}\left(\frac{min}{passenger}\right) \quad (6)$$

- Desk service time: It can be modeled by statistical distributions (Hillier and Lieberman, 2013). Also, the exponential distribution is often used to characterize the time to complete a task.
- Queue configuration and queue discipline: the former refers the usage of a single queue for a counter or multiple counters and, the latter refers to the order in which members of the queue are selected for service (Hillier and Lieberman, 2013). These authors also state that the queue configuration called bank lining (a single queue for multiple counters) and the queue discipline FIFO (First input – First output) are the most common in queue systems.

3.3. Step 3: Adjacent Resource Constraint

Once one have determined the required numbers of desk by interval for each flight, it is possible to minimize the total desk requirements under the adjacent resource constraint. This constraint stipulates that all desks for the same flight should be adjacent. As can be easily understood, the adjacency constraint does not make sense for the common systems as there is no distinction between flights. On the contrary, in a dedicated system there is an adjacency constraint to be met.

Van Dijk and Van der Sluis (2006) explain clearly this theme, and state that without the adjacency constraint, the minimal number of desks could be found easily by the Earliest Release Date First rule (one of the Fixed Interval Scheduling). This procedure would indicate the number of required desks (N_{max}) at the busiest time interval but it would not guarantee an optimal solution satisfying the adjacency constraint. Thus, mathematical models related with the Adjacent Resource Scheduling (ARS) have to guarantee an optimal desk allocation with $\mathrm{N_{max}}$ desks. With this regard, Duin and Van der Sluis (2004) explain the complexity of the ARS and present an integer linear program. Moreover, Van Dijk and Van der Sluis (2006) study the ARS in the airport check-in process and propose a mathematical model too.

This section explains the ARS in order to associate this concept to the ACCAP (Section 3.3.1). Also the mathematical formulation proposed by Van Dijk and Van der Sluis (2006) is presented (Section 3.3.2).

3.3.1. Adjacent Resource Scheduling (ARS)

According to Duin and Van der Sluis (2004), deterministic problems involving the scheduling or sequencing of jobs on machines form a well-studied group of problems in the literature. However, within scheduling and sequencing jobs, the ARS problem has received less attention. This problem considers the minimal number of physical resources for a number of jobs which require resource units during a given time intervals in an adjacent manner. Furthermore, there are two variants of ARS, a basic version named ARS-R and the general version named ARS-V. The former considers jobs with constant resource needs over the time, and the latter, jobs with resource needs that vary over the time.

Considering mathematical notation and using related terms with flights instead of jobs and desks instead of resource, the problem is stated as follows:

A group of check-in desk units $r=1,2,\dots,R$ is to handle flights $j=1,2,\dots,J$ in a planning horizon with time intervals $t=1,2,\dots,T$. Each desk can be assigned to at most one flight per time interval. During the check-in period of a flight $I(j)=[a(j),b(j)]$ with $(b(j)–a(j)+1)$ time intervals in $[1,T]$, each flight j is to be assigned a resource-period of desks $n(j,t)$. Each value of the $n(j,t)$ is in $[1,R]$ and their must overlap maximally for each flight. This constraint of maximum overlap stipulates that flights must re-utilize a number of min *{n(j,t), n(j,t-1)}* units in any next time interval $t \in [a(j),b(j)]$. Most applications typically desire this constraint to minimize the costs associated with change.

An example of ARS-V is given in Table 16a), and his feasible and optimal solution is presented in Table 16b). Table 16c) presents an infeasible solution where the flight 1 has not a maximal overlap at *t=2* and flight 3 does not satisfy the desk-adjacency condition at *t=3*.

Table 16 - An ARS-V instance (a), with feasible solution (b) and infeasible solution (c)

a) n(j,t)

j \ t	1	2	3	4
1	4	1	0	0
2	2	1	2	0
3	0	4	2	1
4	0	0	1	2
5	0	0	0	3

b) Feasible solution

r \ t	1	2	3	4
1	1	1		4
2	1	3	4	4
3	1	3	3	3
4	1	3	3	5
5	2	3	2	5
6	2	2	2	5

c)Infeasible solution

r \ t	1	2	3	4
1	1	3	3	3
2	1	3		4
3	1	3	4	4
4	1	3	3	5
5	2	1	2	5
6	2	2	2	5

Source: Duin and Van der Sluis (2004)

3.3.2. ARS Mathematical Model

This section presents the mathematical model proposed by Van Dijk and Van der Sluis (2006) and used in the ACCAP methodology proposed in this thesis. The following notation is introduced:

- T: time window;
- l: length of the considered time interval;
- f *or* g: representative index of the single flight;
- t: representative index of the single time interval;
- M: set of the time intervals in T or the number of time intervals in T ($M = T/l$);
- F: set of flights scheduled in T;
- a_f: the time interval when the check-in process starts for flight f;
- b_f: the time interval when the check-in process ends for flight f;
- I_f: intervals when check-in process is allowed for flight f ($I_f = [\, a_f, b_f \,]$);
- $n_{f,t}$: required desks for the check-in process of flight f during time interval t;
- $BigM$: big value.

The model considers three sets of decision variables:

- $d_{f,t}$: the largest desk number assigned to flight f during each time interval of I_f;
- $o_{f,g}$: binary variable with $o_{f,g}$= 1 when flight f is assigned to highest desk number than flight g. And $o_{f,g}$= 0 in otherwise.
- D_{max}: the total number of desks required.

The ARS mathematical formulation is as follows:

$$MIN\ Z = D_{max} \tag{3.16}$$

S.t.

$$n_{ft} \leq d_{ft} \leq D_{max} \qquad \forall f \in F,\ \forall t \in [a_f, b_f] \tag{3.17}$$

$$d_{ft} + n_{gt} \leq d_{gt} + BigM * o_{f,g} \qquad \forall f \in F, \forall g \in F, \forall t \in I_f \cap I_g \tag{3.18}$$

$$d_{gt} + n_{ft} \leq d_{ft} + BigM * \left(1 - o_{f,g}\right) \qquad \forall f \in F, \forall g \in F, \forall t \in I_f \cap I_g \tag{3.19}$$

$$d_{ft} - d_{f(t-1)} \leq max\left(0, n_{ft} - n_{f(t-1)}\right) \qquad \forall f \in F,\ \forall t \in [a_f, b_f] \tag{3.20}$$

$$d_{f(t-1)} - d_{ft} \leq max\left(0, n_{f(t-1)} - n_{ft}\right) \qquad \forall f \in F,\ \forall t \in [a_f, b_f] \tag{3.21}$$

$$D_{max}, d_{ft} \geq 0 \qquad \forall f \in F,\ \forall t \in M \tag{3.22}$$

$$o_{f,g} \in \{0,1\} \qquad \forall f \in F,\ \forall g \in F \tag{3.23}$$

The objective function (3.16) minimizes the number of desks needed for all flights. In this way, let us assume that desks are numbered from $1\ to\ D_{max}$. Constraints (3.17) ensure that the desks assigned to a flight fall within the range from $1\ to\ D_{max}$. Considering the adjacency restriction combined with fixed time intervals and a variable allocation policy, the assignment of a flight to desks can be described by the variable $d_{f,t}$ which denotes the largest desk number assigned to flight f in t ($t \in I_f$). Constraints (3.18) and (3.19) ensure that two flights are not assigned to the same desk at the same interval. For that, it is used a binary variable $o_{f,g}$ for rewriting the disjunctive constraint: ($d_{ft} + n_{gt} \leq d_{gt}$ or $d_{gt} + n_{ft} \leq d_{ft}$). Constraints (3.20) and (3.21) avoid that during the check-in period of a flight; desks are opened and closed at the same time. When there is an increase in demand for desks $(n_{f,t} > n_{f,t-1})$ then exactly $(n_{f,t} - n_{f,t-1})$ desks are opened, and when there is a decrease in the demand for desks $(n_{f,t} < n_{f,t-1})$ then exactly $(n_{f,t-1} - n_{f,t})$ desks are closed. Also, these constraints accomplish the maximum overlap which stipulates that the flight f must re-utilize a number of $min\{n(j,t), n(j,t-1)\}$ units in the next time interval $t \in [a(j), b(j)]$. Constraints (3.22) and (3.23) define the domain of the decision variables.

3.4. Work procedure for the ACCAP methodology

This section explains the work procedure that enables the integration of the three Steps of the methodology as shown in Figure 5. This methodology combines optimization and simulation, and it is composed of three steps. Step 1 uses optimization models to determine the optimal number of desks. Step 2 uses simulation to assess if the results obtained in Step 1 meet the overall service level, and to define key parameters of the optimization models. Step 3 uses an optimization model to enforce an adjacent constraint for dedicated systems.

As an overview, it is developed two new optimization models for common and dedicated check-in systems. They were strengthened with the “utilization and fluctuation factors (UFF)” constraints in order to consider queue and stochastic aspects. The values for these factors must be defined taking into account the efficient use of resources and a given service level. For this task, queue theory and terminating simulation are required. The former provides the first magnitudes and insights about the state of the process during each time interval. The latter deepens these insights and gives more information throughout the whole process. Then, two results can be obtained, one for common system and the other for dedicated system. For this latter, it is possible to apply adjacent resource scheduling.

The work procedure for the ACCAP methodology is detailed as follows:

- Step A: Run the ACCAP model without the UFF constraints (equation 4.6 and 4.7 for a common system and equation 4.13 and 4.14 for a dedicated system), and then calculate the required number of check-in desks.
- Step B: First, based on queue theory, collect the most important queue results per time interval and identify possible disruptions about the state of the process during each time interval. The following information is provided:
  - λ: Arrival rate.
  - U: Service rate.
  - Desks (S): Number of servers.
  - Change arrival rate: Change in passenger arrival rate between two adjacent time intervals.
  - Change # servers: Change in the number of servers between two adjacent time intervals.
  - L: Expected number of customers in queue system.
  - L_q: Expected queue length.
  - W: Expected waiting time in system.
  - W_q: Expected waiting time in queue.
  - ρ: utilization factor of queue theory.
- Step B: Second, based on simulation, assess the service level (waiting time and queue size) and quality of service measures (% of passengers waiting less than 10 minutes and % of passengers waiting inside the check-in area). That means to assess the service level during each replication and by time interval. Third, identify the intervals that affect the service level.
- Step C: In order to achieve or improve the service level without resources' overuse, select only time intervals with utilization problems, and for them establish a lower utilization factor. If the problem is in the fluctuation factor, higher values for this factor must be considered in the related time intervals.
- Step D: Run the ACCAP model with the UFF constraints and repeat Step B and Step C until the desired service level is reached.
- Step E: Only for dedicated check-in system, apply the ARS model.

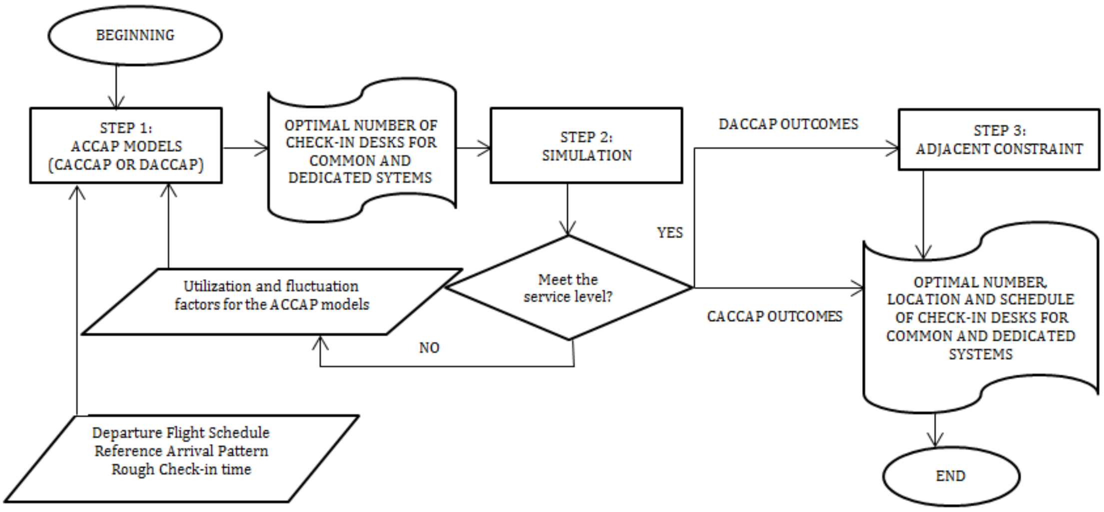


Figure 5 - Overview about the methodology to optimize the ACCAP

3.5. Sample test

The purpose of developing a sample test is to prove the reliability and accuracy of the methodology proposed in this work. The sample test considered here uses the same input data of a case study performed by Van Dijk and Van der Sluis (2006). This information is detailed in Section 3.5.1. Also, additional input data necessary for this example is provided. Section 3.5.2 supports the election of half-hour time intervals. Section 3.5.3 and 3.5.4 present the development of the sample for a common and a dedicated system, respectively. Finally, Section 3.5.5 discusses the relevance of this sample test.

3.5.1. Parameters and assumptions for the sample test

All parameters and assumptions for this sample test are detailed as follows:

- Arrivals distribution: Based on arrival pattern from Table 1.
- Departure flight schedule: Based on the flights list from Table 2.
- Length time interval: 30 minutes.
- Desk service time: 2 minutes (Van Dijk and Van der Sluis, 2006).
- Desk opening cost: USD 80 per hour (Parlar and Sharafali, 2008).
- Queue cost: USD 20 per hour (Parlar and Sharafali, 2008).

- Check-in period: check-in desks open three hours before the flight departure and there are 150 minutes for fulfilling the check-in process (Diaz, 2008).
- Statistical distribution to passenger arrivals: Exponential.
- Statistical distribution for check-in time: Exponential.
- Queue configuration: bank lining.
- Queue discipline: FIFO.
- Service level: Regarding to waiting time, at least 90% of all passengers reach their check-in desk within 10 minutes and no passenger waits more than 35 minutes (α = 10%). Additionally, in terms of queue size, 90% of all passengers must stay inside the check-in area. For that, it is considered that at most 6 people can wait in front of each check-in desk.
- Average utilization desk: over 85%.
- Type of simulation: Terminating simulation.
- Warm-up period: 60 minutes (Explained in Section 3.2).
- Set of results: For performing each simulation experiment, a trial of twenty replications is considered as this number of replications provides similar average queue results.
- Passengers arrive one by one. Although in many real situations passengers arrive in group, this phenomenon does not affect to a certain extent the service at the counters (Diaz, 2008).
- The load factor for any flight is 100% (Van Dijk and Van der Sluis, 2006).
- All passengers arrive before the counters are closed and all of them have to check-in at counters (Van Dijk and Van der Sluis, 2006).

3.5.2. Proper time interval length

For the proposed methodology in this work, the time interval length is a relevant parameter in order to get accurate results from the reality. At first sight, it has to do directly with intervals length available in reference arrival patterns. However, Stolletz (2010) highlights that the "workforce and facilities" planning involved in airport services has to be linked to time intervals of staffing timetables. In this way, the hourly and the half-an-hour are the most common time intervals for constructing work timetables at operational levels. Then, this section addresses the analysis about the proper length of time interval (between hourly and half-hourly) to be used in the methodology to optimize the ACCAP.

For this section, two cases are presented, the hourly interval is considered in Case 1 and the half-hourly interval in Case 2. Only common systems are analyzed as the conclusions can be extended to dedicated systems. Next, the procedure for this experiment is explained.

- First, run the ACCAP model without the UFF constraints (equation 3.6 and 3.7) and then calculate the required number of check-in desks.
- Based on the outcome of first step (number of desks by time interval) and using terminating simulation, get the most important queue features (average waiting time and queue size) and their general statistics.
- Look at the general statistics and choose the time interval length which provides better values for the queue features.

After performed this procedure using the input data from Section 3.5.1, general statistics about the main queue results for each case are obtained as shown in Table 17. Looking at this table and comparing Case 1 and Case 2, the latter provides better queue results. So, half-an-hour represents the proper length of time interval and this statement is considered for any section of this work.

Table 17 - General statistics of main queue results for Case 1 and Case 2

CASE	**CASE I**					**CASE II**				
Data Type	**WAITING TIME**		**NUMBER WAITING**		**NUMBER OUT**	**WAITING TIME**		**NUMBER WAITING**		**NUMBER OUT**
Statistic Type	**Ave**	**Max**	**Ave**	**Max**	**Ave**	**Ave**	**Max**	**Ave**	**Max**	**Ave**
Mean	***4.66***	***24.33***	***18.31***	***72.95***	***2161.00***	***2.61***	***16.65***	***10.10***	***48.60***	***2171.15***
Variance	***2.99***	***85.01***	***50.69***	***284.45***	***1994.20***	***2.12***	***32.45***	***33.27***	***360.04***	***2614.43***
Standard deviation	***1.73***	***9.22***	***7.12***	***16.87***	***44.66***	***1.46***	***5.70***	***5.77***	***18.97***	***51.13***
Max	***10.67***	***46.44***	***42.58***	***114.00***	***2243.00***	***7.67***	***30.77***	***29.92***	***94.00***	***2311.00***

3.5.3. Sample test – CACCAP

In this section, the work procedure of the methodology to optimize the ACCAP is performed considering the common check-in system. Every step involved in the methodology is explained as follows:

a) Applying Step A, the number of desks to be assigned during each time interval (B_t) is obtained and shown in Table 18.

Table 18 - Number of desks for CACCAP (without constraints 4.6 and 4.7) and CACCAP

Time Interval	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
CACCAP (No 4.6–4.7)	*2*	*2*	*6*	*5*	*11*	*9*	*14*	*10*	*12*	*6*	*8*	*6*	*11*	*10*	*15*	*11*	*11*	*4*	*3*	*0*
CACCAP	*2*	*3*	*6*	*5*	*11*	*9*	*14*	*10*	*12*	*7*	*9*	*7*	*11*	*10*	*15*	*11*	*11*	*6*	*3*	*0*

b1) Applying Step B and queue theory, the main queue features regarding each time interval are provided in Table 19. They evince some congestion during time intervals 2 and 11, as the utilization factors are over 97%. The analysis by simulation is much deeper than queue theory, so is explained in step b2).

Table 19 - Queue results for CACCAP model (without constraints 4.6 and 4.7)

Time interval	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Length (min)	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*	*30*
Passengers	*23*	*30*	*77*	*72*	*148*	*126*	*198*	*138*	*167*	*84*	*117*	*72*	*157*	*138*	*216*	*150*	*153*	*54*	*40*
λ	*0.77*	*1.00*	*2.57*	*2.40*	*4.93*	*4.20*	*6.60*	*4.60*	*5.57*	*2.80*	*3.90*	*2.40*	*5.23*	*4.60*	*7.20*	*5.00*	*5.10*	*1.80*	*1.33*
U	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
Desks (S)	*2*	***2***	*6*	*5*	*11*	*9*	*14*	*10*	*12*	***6***	***8***	***6***	*11*	*10*	*15*	*11*	*11*	***4***	***3***
Change arrival rate		*1.30*	*2.57*	*0.94*	*2.06*	*0.85*	*1.57*	*0.70*	*1.21*	***0.50***	*1.39*	***0.62***	*2.18*	*0.88*	*1.57*	*0.69*	*1.02*	***0.35***	***0.74***
Change # servers		*1.00*	*3.00*	*0.83*	*2.20*	*0.82*	*1.56*	*0.71*	*1.20*	***0.50***	*1.33*	***0.75***	*1.83*	*0.91*	*1.50*	*0.73*	*1.00*	***0.36***	***0.75***
L	*3.8*	***x***	*9.0*	*26.4*	*15.4*	*19.4*	*25.9*	*17.6*	*20.6*	*17.1*	***43.7***	*6.9*	*26.4*	*17.6*	*34.3*	*16.8*	*19.6*	*10.7*	*8.9*
Lq	*2.2*	***x***	*3.8*	*21.6*	*5.6*	*11.0*	*12.7*	*8.4*	*9.5*	*11.5*	***35.9***	*2.1*	*15.9*	*8.4*	*19.9*	*6.8*	*9.4*	*7.1*	*6.2*
W	*4.9*	***x***	*3.5*	*11.0*	*3.1*	*4.6*	*3.9*	*3.8*	*3.7*	*6.1*	***11.2***	*2.9*	*5.0*	*3.8*	*4.8*	*3.4*	*3.9*	*5.9*	*6.7*
Wq	*2.9*	***x***	*1.5*	*9.0*	*1.1*	*2.6*	*1.9*	*1.8*	*1.7*	*4.1*	***9.2***	*0.9*	*3.0*	*1.8*	*2.8*	*1.4*	*1.9*	*3.9*	*4.7*
$\rho = \lambda / (S*U)$	*0.77*	***1.00***	*0.86*	*0.96*	*0.90*	*0.93*	*0.94*	*0.92*	*0.93*	*0.93*	***0.98***	*0.80*	*0.95*	*0.92*	*0.96*	*0.91*	*0.93*	*0.90*	*0.89*

b2) Considering terminating simulation, the main queue results and service level measures for each replication are shown in Table 20 and 21, respectively. The passengers meeting the service level is more than 90% and that indicates that the system works fine. However, examining each replication by time intervals, there are some intervals where the service level is not met. Thus, analyzing each replication is required. In order to scrutinize each replication, only the assessment of replication number two (R2) is developed as example. Based on Table 21, the R2 contains 149 passengers waiting more than 10 minutes and 73 passengers do not fit in the check-in area. This forces to resort for detailed information of R2 that is presented in Table 22 and Figure 6. Thus, it is possible to note that intervals 2, 10 and 11 could exhibit problems of waiting time and queue size. Regarding to waiting time, there are 6, 84 and 59 passengers waiting more than 10 minutes during time intervals 2, 10 and 11, respectively. And they represent the 20%, 100% and 50% of passengers of each interval, respectively. Regarding, to queue size, there are 73 passengers staying out the check-in area during interval 10 and they represent the 87% of passengers of that interval. This assessment carried out to R2 must be extended to all replications that present service level problems. Then, time intervals 2, 10, 11, 12, 18 and 19 impact directly in the service level as shown in Table 22. In addition, consecutive intervals (10, 11 and 12 or 18 and 19) indicate propagation problems to the closest immediate intervals.

Table 20 - Queue results for CACCAP model (without constraints 4.6 and 4.7)

Data type	WAITING TIME		NUMBER WAITING		NUMBER OUT
Replication	Ave	Max	Ave	Max	Ave
1	1.20	15.97	4.60	26.00	2182
2	3.29	19.14	12.86	53.00	2229
3	1.49	14.24	5.63	37.00	2155
4	1.52	7.39	5.99	29.00	2250
5	3.19	16.00	12.37	40.00	2204
6	1.30	15.00	5.14	34.00	2227
7	1.35	22.17	5.07	30.00	2077
8	2.24	16.70	8.39	36.00	2112
9	1.88	12.09	7.24	43.00	2188
10	1.69	22.34	6.41	44.00	2118
11	2.18	14.00	8.13	48.00	2131
12	2.23	11.62	8.53	44.00	2167
13	2.83	12.18	11.06	48.00	2215
14	2.20	11.70	8.21	38.00	2126
15	1.02	10.16	3.93	24.00	2190
16	1.94	15.13	7.26	42.00	2134
17	3.11	15.74	11.93	52.00	2190
18	1.36	8.89	5.11	27.00	2144
19	3.43	11.62	13.33	58.00	2208
20	2.18	15.93	8.33	45.00	2182
Mean	2.08	14.40	7.98	39.90	2171.45
Variance	0.53	14.60	8.15	87.09	1975.25
Standard deviation	0.73	3.82	2.86	9.33	44.44
Max	3.43	22.34	13.33	58.00	2250.00

Table 21 - Service level measures for CACCAP model (without constraints 4.6 and 4.7)

Replication	WAITING TIME			NUMBER WAITING			Total Passengers	Problem - Time Interval
	% Pass < 10 min	Pass < 10 min	Pass > 10 min	% In check-in area	Pass In check-in area	Pass Out check-in area		
1	1.00	2176	6	1.00	2181	1	2182	2
2	**0.93**	**2080**	**149**	**0.97**	**2156**	**73**	**2229**	**2 - 10 - 11**
3	1.00	2148	7	0.99	2140	15	2155	2
4	1.00	2250	0	1.00	2250	0	2250	
5	0.94	2082	122	0.98	2157	47	2204	2 - 12 - **18** - 19
6	0.99	2203	24	1.00	2227	0	2227	19
7	0.96	2000	77	0.98	2042	35	2077	**18** - 19
8	0.95	2003	109	0.97	2057	55	2112	2 - **18** – 19
9	0.99	2159	29	1.00	2188	0	2188	**10**
10	0.98	2081	37	0.99	2104	14	2118	**18** – 19
11	0.95	2031	100	0.99	2113	18	2131	**10** – 11
12	0.99	2136	31	1.00	2167	0	2167	11
13	0.97	2158	57	1.00	2213	2	2215	**10**
14	0.99	2097	29	1.00	2124	2	2126	**12**
15	1.00	2189	1	1.00	2190	0	2190	
16	0.97	2066	68	0.99	2117	17	2134	**12**
17	0.97	2117	73	0.99	2169	21	2190	11 – **12**
18	1.00	2144	0	1.00	2144	0	2144	
19	0.99	2181	27	1.00	2208	0	2208	**10**
20	0.94	2048	134	0.99	2155	27	2182	**10 – 12**
TOTAL	0.98	42349	1080	0.9925	43102	327	43429	**10 - 12 – 18**

Table 22 - Detailed information about each time interval with service level problems

CACCAP MODEL (WITHOUT CONSTRAINTS 4.6 AND 4.7)						
Time Interval	**Pass > 10 min**	**Replication**	**Pass Out check-in area**	**Replication**	**Impact - Waiting Time**	**Impact - Queue size**
2	*6*	*1*	*1*	*1*	*3.15%*	*5.50%*
	6	*2*	*15*	*3*		
	7	*3*	*2*	*5*		
	15	*8*				
10	*84*	*2*	*73*	*2*	*33.80%*	*33.03%*
	29	*9*	*18*	*11*		
	84	*11*	*2*	*13*		
	57	*13*	*15*	*20*		
	27	*19*				
	84	*20*				
11	*59*	*2*			*9.90%*	*0.00%*
	16	*11*				
	31	*12*				
	1	*17*				
12	*34*	*5*	*2*	*14*	*23.52%*	*15.90%*
	29	*14*	*17*	*16*		
	1	*15*	*21*	*17*		
	68	*16*	*12*	*20*		
	72	*17*				
	50	*20*				
18	*54*	*5*	*41*	*5*	*16.67%*	*39.76%*
	54	*7*	*35*	*7*		
	54	*8*	*54*	*8*		
	18	*10*				
19	*34*	*5*	*4*	*5*	*12.96%*	*5.81%*
	24	*6*	*1*	*8*		
	23	*7*	*14*	*10*		
	40	*8*				
	19	*10*				
Total	*1080*		*327*		*100.00%*	*100.00%*

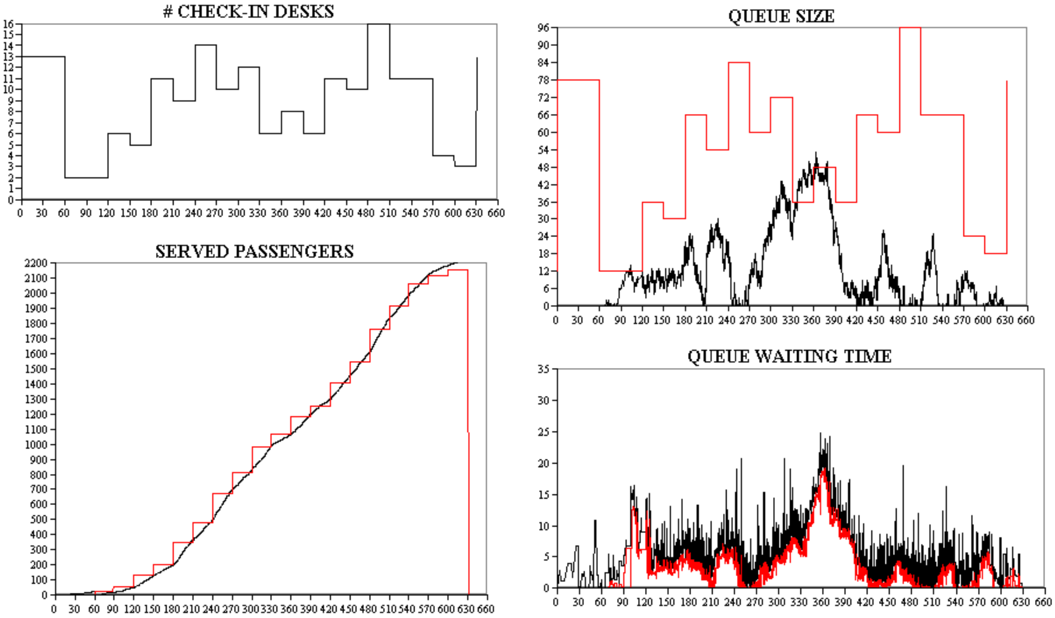


Figure 6 -Queue results of R2 for CACCAP model (without constraints 4.6 and 4.7)

c) Following Step C, the utilization factor must be less than or equal to 97% for time intervals 2 and 11. Also, the fluctuation factors must be more than 50% for interval 10, 35% for interval 18; and more than 75% for interval 12. These upper and lower bounds can be seen in Table 19.

d) Applying Step D, the main queue results and the service level measures for each replication are shown in Table 23 and 24, respectively. In overall way, the service level is met. Focusing in each replication and each time interval, only replication 17 could exhibit problems regarding to waiting time. But, at the same time, the maximum waiting time in that replication is 14.57 minutes which is quite acceptable. Then, the objective of reducing the negative impact of time intervals which present service level problems is attained. In this way, taking into account the number of passengers out of service level between the two main stages (Step A and Step D), 83% of reduction to waiting time and 92% of reduction to queue size are achieved. Final results about the number of required desks are shown in Table 18. Comparing them with the ones of Step a), the original number of desks for time intervals 2, 10, 11 and 12 is increased in one unit, and the time interval 18 in two units.

Table 23 - Queue results and general statistics for CACCAP model

Data type	WAITING TIME		NUMBER WAITING		NUMBER OUT
Replication	Ave	Max	Ave	Max	Ave
1	*3.58*	*12.57*	*14.25*	*55.00*	*2270*
2	*1.59*	*11.27*	*6.17*	*47.00*	*2217*
3	*1.35*	*8.78*	*5.15*	*36.00*	*2161*
4	*1.39*	*8.85*	*5.59*	*33.00*	*2281*
5	*0.83*	*10.57*	*3.06*	*22.00*	*2116*
6	*0.74*	*7.05*	*2.90*	*22.00*	*2249*
7	*0.86*	*6.82*	*3.22*	*24.00*	*2134*
8	*1.33*	*10.58*	*4.92*	*31.00*	*2103*
9	*1.87*	*9.13*	*7.35*	*41.00*	*2241*
10	*1.39*	*7.56*	*5.27*	*44.00*	*2159*
11	*1.39*	*6.56*	*5.22*	*36.00*	*2145*
12	*1.12*	*6.27*	*4.26*	*32.00*	*2173*
13	*0.82*	*7.07*	*3.15*	*24.00*	*2181*
14	*1.35*	*10.09*	*4.96*	*29.00*	*2101*
15	*1.25*	*9.92*	*4.78*	*24.00*	*2184*
16	*2.04*	*10.20*	*7.78*	*43.00*	*2178*
17	*2.74*	*14.57*	*10.50*	*47.00*	*2185*
18	*1.39*	*8.66*	*5.29*	*29.00*	*2166*
19	*0.99*	*6.23*	*3.76*	*31.00*	*2161*
20	*1.00*	*14.70*	*3.78*	*22.00*	*2164*
Mean	*1.45*	*9.37*	*5.57*	*33.60*	*2178.45*
Variance	*0.45*	*6.14*	*7.15*	*90.94*	*2471.05*
Standard deviation	*0.67*	*2.48*	*2.67*	*9.54*	*49.71*
Max	*3.58*	*14.70*	*14.25*	*55.00*	*2281.00*

Table 24 - Service level measures for CACCAP model

Replication	WAITING TIME % Pass < 10 min	Pass < 10 min	Pass > 10 min	NUMBER WAITING % In check-in area	Pass In check-in area	Pass Out check-in area	Total Passengers	Problem - Time Interval
1	*0.987*	*2241*	*29*	*1.000*	*2270*	*0*	*2270*	*15 – 16*
2	*0.996*	*2209*	*8*	*1.000*	*2217*	*0*	*2217*	*7*
3	*1.000*	*2161*	*0*	*1.000*	*2161*	*0*	*2161*	
4	*1.000*	*2281*	*0*	*1.000*	*2281*	*0*	*2281*	
5	*1.000*	*2115*	*1*	*1.000*	*2116*	*0*	*2116*	
6	*1.000*	*2249*	*0*	*1.000*	*2249*	*0*	*2249*	
7	*1.000*	*2134*	*0*	*1.000*	*2134*	*0*	*2134*	
8	*1.000*	*2102*	*1*	*1.000*	*2103*	*0*	*2103*	
9	*1.000*	*2241*	*0*	*1.000*	*2241*	*0*	*2241*	
10	*1.000*	*2159*	*0*	*1.000*	*2159*	*0*	*2159*	
11	*1.000*	*2145*	*0*	*1.000*	*2145*	*0*	*2145*	
12	*1.000*	*2173*	*0*	*1.000*	*2173*	*0*	*2173*	
13	*1.000*	*2181*	*0*	*1.000*	*2181*	*0*	*2181*	
14	*1.000*	*2100*	*1*	*1.000*	*2101*	*0*	*2101*	
15	*1.000*	*2184*	*0*	*1.000*	*2184*	*0*	*2184*	
16	*1.000*	*2177*	*1*	*1.000*	*2177*	*1*	*2178*	
17	*0.938*	*2049*	*136*	*0.995*	*2173*	*12*	*2185*	*8 - 10 – 12*
18	*1.000*	*2166*	*0*	*1.000*	*2166*	*0*	*2166*	
19	*1.000*	*2161*	*0*	*1.000*	*2161*	*0*	*2161*	
20	*0.997*	*2158*	*6*	*1.000*	*2163*	*1*	*2164*	*1 – 2*
TOTAL	*0.996*	*43386*	*183*	*1.000*	*43555*	*14*	*43569*	

From the queue and simulation analysis of this section, one may derive the following conclusions and suggestions:

- Regarding to time intervals 2 and 11, it is inferred that the utilization factor must be less than or equal to 97%. Also, if the following time interval of them presents a decrease in passenger arrival rate, there could be the propagation problems to the closest immediate intervals. This is the case of time interval 12 whose fluctuation factor must be more than 75% (see Table 19).
- Regarding to time intervals 10 and 18, both intervals present a decrease in passenger arrival rate over 45% (see Table 19). Thus, it is inferred that their fluctuation factors must be more than 50%.
- A particular situation of the propagation problems to the closest immediate intervals is noted regarding to interval 19. This interval did not suffer modifications in the number of required desks (see Table 18) because the problems are originated in the former time interval.

3.5.4. Sample test – DACCAP

In this Section the work procedure is performed considering the sample test and a dedicated system. Based on the flight schedule shown in Table 2, there are six types of flights according to the number of passengers. The analysis is performed to one type of them (flight of 270 passengers) as example. Every step involved in the methodology is explained as follows:

a) Following Step A, the number of desks to be assigned for each flight by time interval ($Desk_{j,t}$) is obtained and shown in Table 25.

Table 25 - Number of desks for DACCAP (without constraints 4.13 and 4.14) and DACCAP

Time Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DACCAP (No 4.13-4.14)	*2*	*3*	*7*	*6*	*12*	*10*	*16*	*11*	*13*	*7*	*10*	*6*	*13*	*11*	*17*	*12*	*12*	*4*	*3*	*0*
DACCAP	*2*	*3*	*7*	*6*	*12*	*11*	*16*	*12*	*13*	*8*	*10*	*6*	*13*	*12*	*17*	*13*	*12*	*5*	*3*	*0*

b1) Applying Step B and queue theory, the main queue features are shown in Table 26 and no congestion is noted in the system.

Table 26 - Queue results for DACCAP model (without constraints 4.13 and 4.14)

Flight	Time Interval	Length (min)	Pass	λ	U	Desks (S)	Change arrival rate	Change # servers	L	Lq	Max Lq Accep	W	Wq	ρ = λ/(S*U)
150	*1*	*30*	*23*	*0.77*	*0.50*	*2*			*3.78*	*2.24*	*12*	*4.9*	*2.91*	*0.767*
	2	*30*	*30*	*1.00*	*0.50*	*3*	*1.30*	*1.500*	*2.89*	*0.89*	*18*	*2.89*	*0.89*	*0.667*
	3	*30*	*45*	*1.50*	*0.50*	*4*	*1.50*	*1.333*	*4.53*	*1.53*	*24*	*3.02*	*1.02*	*0.750*
	4	*30*	*30*	*1.00*	*0.50*	*3*	*0.67*	*0.750*	*2.89*	*0.89*	*18*	*2.89*	*0.89*	*0.667*
	5	*30*	*22*	*0.73*	*0.50*	*2*	*0.73*	*0.667*	*3.13*	*1.67*	*12*	*4.28*	*2.28*	*0.733*
210	*1*	*30*	*32*	*1.07*	*0.50*	*3*			*3.41*	*1.27*	*18*	*3.19*	*1.2*	*0.711*
	2	*30*	*42*	*1.40*	*0.50*	*3*	*1.31*	*1.000*	*15.07*	*12.27*	*18*	*10.77*	*8.77*	*0.933*
	3	*30*	*63*	*2.10*	*0.50*	*5*	*1.50*	*1.667*	*7.53*	*3.33*	*30*	*3.58*	*1.58*	*0.840*
	4	*30*	*42*	*1.40*	*0.50*	***3***	*0.67*	***0.600***	*15.07*	*12.27*	*18*	*10.77*	*8.77*	*0.933*
	5	*30*	*31*	*1.03*	*0.50*	*3*	*0.74*	*1.000*	*3.1*	*1.04*	*18*	*3*	*1*	*0.689*
240	*1*	*30*	*36*	*1.20*	*0.50*	*3*			*5*	*2.6*	*18*	*4.16*	*2.16*	*0.800*
	2	*30*	*48*	*1.60*	*0.50*	*4*	*1.33*	*1.333*	*5.59*	*2.39*	*24*	*3.5*	*1.5*	*0.800*
	3	*30*	*72*	*2.40*	*0.50*	*6*	*1.50*	*1.500*	*6.87*	*2.07*	*36*	*2.86*	*0.86*	*0.800*
	4	*30*	*48*	*1.60*	*0.50*	*4*	*0.67*	*0.667*	*5.5*	*2.39*	*24*	*3.5*	*1.5*	*0.800*
	5	*30*	*36*	*1.20*	*0.50*	*3*	*0.75*	*0.750*	*5*	*2.6*	*18*	*4.16*	*2.16*	*0.800*
180	*1*	*30*	*27*	*0.90*	*0.50*	*2*			*9.47*	*7.67*	*12*	*10.52*	*8.52*	*0.900*
	2	*30*	*36*	*1.20*	*0.50*	*3*	*1.33*	*1.500*	*5*	*2.6*	*18*	*4.2*	*2.16*	*0.800*
	3	*30*	*54*	*1.80*	*0.50*	*4*	*1.50*	*1.333*	*10.69*	*7.09*	*24*	*5.94*	*3.94*	*0.900*
	4	*30*	*36*	*1.20*	*0.50*	***3***	*0.67*	***0.750***	*5*	*2.6*	*18*	*4.16*	*2.16*	*0.800*
	5	*30*	*27*	*0.90*	*0.50*	*2*	*0.75*	*0.667*	*9.47*	*7.67*	*12*	*10.53*	*8.53*	*0.900*
270	*1*	*30*	*41*	*1.37*	*0.50*	*3*			*11.6*	*8.86*	*18*	*8.45*	*6.47*	*0.911*
	2	*30*	*54*	*1.80*	*0.50*	*4*	*1.32*	*1.333*	*10.69*	*7.09*	*24*	*5.94*	*3.94*	*0.900*
	3	*30*	*81*	*2.70*	*0.50*	*6*	*1.50*	*1.500*	*12.06*	*6.66*	*36*	*4.47*	*2.47*	*0.900*
	4	*30*	*54*	*1.80*	*0.50*	***4***	*0.67*	***0.667***	*10.69*	*7.09*	*24*	*5.94*	*3.94*	*0.900*
	5	*30*	*40*	*1.33*	*0.50*	*3*	*0.74*	*0.750*	*8.87*	*6.21*	*18*	*6.67*	*4.67*	*0.889*
300	*1*	*30*	*45*	*1.50*	*0.50*	*4*			*4.53*	*1.53*	*24*	*3.02*	*1.02*	*0.750*
	2	*30*	*60*	*2.00*	*0.50*	*5*	*1.33*	*1.250*	*6.22*	*2.22*	*30*	*3.11*	*1.11*	*0.800*
	3	*30*	*90*	*3.00*	*0.50*	*7*	*1.50*	*1.400*	*9.68*	*3.68*	*42*	*3.28*	*1.28*	*0.857*
	4	*30*	*60*	*2.00*	*0.50*	*5*	*0.67*	*0.714*	*6.22*	*2.22*	*30*	*3.11*	*1.11*	*0.800*
	5	*30*	*45*	*1.50*	*0.50*	*4*	*0.75*	*0.800*	*4.53*	*1.53*	*24*	*3.02*	*1.02*	*0.750*

b2) Considering simulation, the main queue results and service level measures for each replication are shown in Table 27 and Table 28, respectively. To scrutinize each replication, only the assessment of replication number nine (R9) is developed as example. Based on Table 28, the R9 contains 117 passengers waiting more than 10 minutes and 95 passengers staying out the check-in area. More information about R9 is provided in Table 29 and Figure 7. From them, it is possible to note that time intervals 3, 4 and 5 could exhibit problems of waiting time and queue size. Regarding to waiting time, there are 23, 54 and 40 passengers waiting more than 10 minutes in these time intervals, respectively. And they represent the 28%, 100% and 100% of passengers of each time interval, respectively. Regarding to queue size, there are 54 and 40 passengers staying out the check-in area and they represent the 100% of time intervals 4 and 5, respectively. This assessment carried out to R9 must be extended to all replications that present service level problems. Then, time intervals 4 and 5 impact directly in the service level as shown in Table 29. As in the CACCAP case this evidences reveal a propagation effect.

Table 27 - Queue results for DACCAP model (without constraints 4.13 and 4.14)

Data type	**WAITING TIME**		**NUMBER WAITING**		**NUMBER OUT**
Replication	**Ave**	**Max**	**Ave**	**Max**	**Ave**
1	*4.85*	*13.26*	*8.99*	*26.00*	*277*
2	*2.29*	*11.38*	*4.37*	*17.00*	*271*
3	*1.49*	*6.50*	*2.79*	*16.00*	*282*
4	*7.57*	*28.12*	*16.99*	*52.00*	*278*
5	*0.89*	*4.30*	*1.72*	*9.00*	*286*
6	*2.60*	*11.07*	*5.17*	*21.00*	*297*
7	*1.38*	*7.00*	*2.40*	*12.00*	*257*
8	*3.17*	*9.30*	*6.03*	*16.00*	*275*
9	*8.38*	*22.52*	*17.30*	*42.00*	*282*
10	*5.25*	*15.71*	*9.84*	*25.00*	*279*
11	*5.64*	*26.14*	*10.69*	*31.00*	*256*
12	*1.44*	*7.40*	*2.75*	*11.00*	*279*
13	*2.51*	*9.50*	*5.01*	*15.00*	*289*
14	*3.27*	*20.83*	*6.11*	*25.00*	*268*
15	*1.21*	*6.30*	*2.18*	*10.00*	*261*
16	*3.53*	*11.30*	*6.94*	*23.00*	*289*
17	*3.11*	*7.00*	*5.36*	*18.00*	*256*
18	*7.95*	*17.00*	*15.78*	*34.00*	*281*
19	*2.52*	*13.74*	*4.47*	*18.00*	*254*
20	*2.71*	*8.77*	*4.98*	*15.00*	*274*
Mean	*3.59*	*12.86*	*6.99*	*21.80*	*274.55*
Variance	*4.97*	*44.80*	*22.30*	*116.06*	*146.05*
Standard deviation	*2.23*	*6.69*	*4.72*	*10.77*	*12.09*
Max	*8.38*	*28.12*	*17.30*	*52.00*	*297.00*

Table 28 - Service level measures for DACCAP model (without constraints 4.13 and 4.14)

Replication	WAITING TIME % Pass < 10 min	Pass < 10 min	Pass > 10 min	NUMBER WAITING % In check-in area	Pass In check-in area	Pass Out check-in area	Total Passengers	Problem – Time Interval
1	*0.81*	*225*	*52*	*0.95*	*263*	*14*	*277*	***4 – 5***
2	*0.99*	*267*	*4*	*1.00*	*271*	*0*	*271*	
3	*1.00*	*282*	*0*	*1.00*	*282*	*0*	*282*	
4	*0.72*	*201*	*77*	*0.85*	*237*	*41*	*278*	***4 – 5***
5	*1.00*	*286*	*0*	*1.00*	*286*	*0*	*286*	
6	*0.99*	*293*	*4*	*1.00*	*297*	*0*	*297*	*4*
7	*1.00*	*257*	*0*	*1.00*	*257*	*0*	*257*	
8	*1.00*	*275*	*0*	*1.00*	*275*	*0*	*275*	
9	*0.59*	*165*	*117*	*0.66*	*187*	*95*	*282*	***4 – 5***
10	*0.85*	*236*	*43*	*0.99*	*275*	*4*	*279*	*5*
11	*0.85*	*217*	*39*	*0.98*	*251*	*5*	*256*	***4 – 5***
12	*1.00*	*279*	*0*	*1.00*	*279*	*0*	*279*	
13	*1.00*	*289*	*0*	*1.00*	*289*	*0*	*289*	
14	*0.91*	*244*	*24*	*1.00*	*267*	*1*	*268*	***5***
15	*1.00*	*261*	*0*	*1.00*	*261*	*0*	*261*	
16	*0.94*	*273*	*16*	*0.95*	*274*	*15*	*289*	***5***
17	*1.00*	*256*	*0*	*1.00*	*256*	*0*	*256*	
18	*0.63*	*177*	*104*	*0.82*	*230*	*51*	*281*	***4 – 5***
19	*0.97*	*246*	*8*	*1.00*	*254*	*0*	*254*	*5*
20	*1.00*	*274*	*0*	*1.00*	*274*	*0*	*274*	
TOTAL	*0.91*	*5003*	*488*	*0.9588*	*5265*	*226*	*5491*	***4 – 5***

Table 29 - Information about each time intervals with service level problems

DACCAP MODEL (WITHOUT CONSTRAINTS 4.13 AND 4.14) Time Interval	Pass > 10 min	Replication	Pass Out check-in area	Replication	Impact – Waiting Time	Impact – Queue size
3	*23*	*9*	*1*	*9*	*6.80%*	*0.44%*
	10	*18*		*18*		
4	*30*	*1*	*8*	*1*	*47.00%*	*54.42%*
	4	*2*		*2*		
	37	*4*	*11*	*4*		
	4	*6*		*6*		
	54	*9*	*54*	*9*		
	23	*10*	*4*	*10*		
	9	*11*		*11*		
	16	*16*	*15*	*16*		
	54	*18*	*31*	*18*		
5	*22*	*1*	*6*	*1*	*46.20%*	*45.14%*
	40	*4*	*30*	*4*		
	40	*9*	*40*	*9*		
	20	*10*		*10*		
	30	*11*	*5*	*11*		
	24	*14*	*1*	*14*		
	40	*18*	*20*	*18*		
	8	*19*		*19*		
Total	*488*		*226*		*100.00%*	*100.00%*

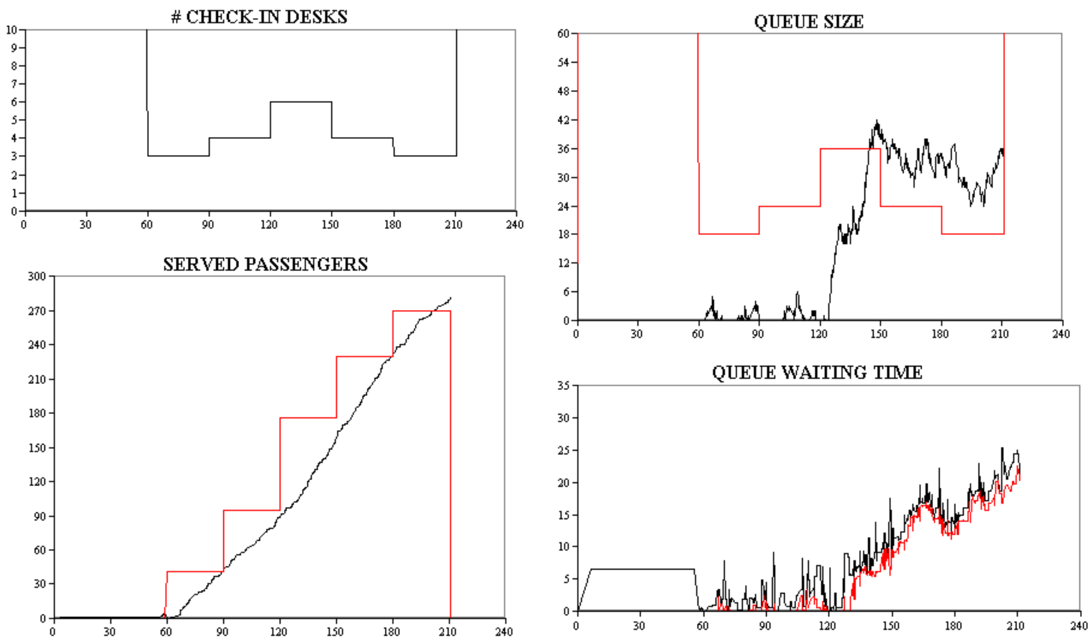


Figure 7 -Queue results of R9 for DACCAP model (without constraints 4.13 and 4.14)

c) Following Step C, fluctuation factor must be more than 67% for time interval 4 (see Table 26).

d) Applying Step D, the main queue results and the service level measures for each replication are shown in Table 30 and Table 31, respectively. The overall service level is met. Focusing in each replication and each time interval, the replications 4, 9 and 18 could exhibit problems regarding to waiting time. But, at the same time, the maximum waiting time for them is less than 20 minutes which is quite acceptable. Also, considering the number of passengers out of service level between the two main stages (Step A and Step D), 53% of reduction to waiting time and 62% of reduction to queue size are achieved. Final results about the number of required desks are shown in Table 32. Comparing them with the ones of Step a), the original number of desks for time interval 4 is increased in one unit.

Table 30 - Queue results and general statistics for DACCAP model

Data type	WAITING TIME		NUMBER WAITING		NUMBER OUT
Replication	Ave	Max	Ave	Max	Ave
1	2.43	8.96	4.54	25.00	277
2	0.92	4.32	1.72	9.00	279
3	2.04	12.37	4.07	19.00	273
4	5.95	14.95	12.54	36.00	302
5	1.25	7.22	2.47	14.00	291
6	1.94	7.77	3.86	21.00	301
7	1.34	6.92	2.43	12.00	271
8	1.78	5.46	3.20	16.00	265
9	5.51	14.62	11.39	42.00	304
10	2.58	7.98	4.75	25.00	276
11	2.59	8.01	4.74	21.00	272
12	0.55	4.14	1.01	7.00	268
13	0.76	6.13	1.39	10.00	272
14	1.63	10.47	3.22	17.00	271
15	1.15	6.30	2.09	11.00	264
16	1.98	7.70	3.86	14.00	292
17	2.55	9.27	4.50	18.00	261
18	6.94	14.43	13.99	33.00	291
19	1.78	10.77	3.10	14.00	249
20	2.16	8.77	4.02	15.00	274
Mean	2.39	8.83	4.64	18.95	277.65
Variance	2.86	9.95	12.61	81.85	206.23
Standard deviation	1.69	3.15	3.55	9.05	14.36
Max	6.94	14.95	13.99	42.00	304.00

Table 31 - Service level measures of the DACCAP model

Replication	WAITING TIME % Pass < 10 min	Pass < 10 min	Pass > 10 min	NUMBER WAITING % In check-in area	Pass In check-in area	Pass Out check-in area	Total Passengers	Problem - Time Interval
1	1.00	277	0	1.00	277	0	277	
2	1.00	279	0	1.00	279	0	279	
3	0.99	269	4	1.00	273	0	273	
4	0.66	200	102	0.90	273	29	302	4 – 5
5	1.00	291	0	1.00	291	0	291	
6	1.00	301	0	1.00	301	0	301	
7	1.00	271	0	1.00	271	0	271	
8	1.00	265	0	1.00	265	0	265	
9	0.86	260	44	0.90	274	30	304	3 – 4
10	1.00	276	0	1.00	276	0	276	
11	1.00	272	0	1.00	272	0	272	
12	1.00	268	0	1.00	268	0	268	
13	1.00	272	0	1.00	272	0	272	
14	1.00	271	0	1.00	271	0	271	
15	1.00	264	0	1.00	264	0	264	
16	1.00	292	0	1.00	292	0	292	
17	1.00	261	0	1.00	261	0	261	
18	0.72	210	81	0.91	265	26	291	4 – 5
19	1.00	249	0	1.00	249	0	249	
20	1.00	274	0	1.00	274	0	274	
TOTAL	0.96	5322	231	0.9847	5468	85	5553	3 - 4 – 5

From the queue and simulation analysis of this section, one may derive the following conclusions and suggestions:

- Regarding to the utilization factor, there are no evidences of problems. Thus, it is inferred that it must be less than or equal to 91%.
- Regarding to time interval 4, it presents a decrease in passenger arrival rate over 33% (see Table 26). Thus, it is inferred that their fluctuation factors must be more than 67%.
- There is no change in time interval 5 because the problems are originated in the former timer interval.
- For dedicated check-in system there are fewer passengers by time interval than a common system. For that reason, reaching the service level by time interval can mean an overuse the resources. So, improving the quality of service by time interval must be the target and each type of flight must be scrutinized independently. With this regard, only the flight of 180 passengers is altered and his original number of desks is increased in one unit (in time interval 4).

e) Following Step E and considering the results for DACCAP (see Table 32), Table 33 shows the desks arrangement that satisfy the ARS.

Table 32 - Number of required desks for DACCAP outcome (Sample test)

Time interval \\ Flight	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	*2*	*3*	*4*	*3*	*2*														
2			*3*	*3*	*5*	*4*	*3*												
3					*3*	*4*	*6*	*4*	*3*										
4					*2*	*3*	*4*	*4*	*2*										
5							*3*	*4*	*6*	*5*	*3*								
6									*2*	*3*	*4*	*3*	*2*						
7											*3*	*3*	*5*	*4*	*3*				
8													*4*	*5*	*7*	*5*	*4*		
9													*2*	*3*	*4*	*4*	*2*		
10															*3*	*4*	*6*	*5*	*3*
Desks by time inerval	*2*	*3*	*7*	*6*	*12*	*11*	*16*	*12*	*13*	*8*	*10*	*6*	*13*	*12*	*17*	*13*	*12*	*5*	*3*

Table 33 - Scheduling for the DACCAP outcome satisfying ARS (Sample test)

Time interval \\ Desk number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	*1*	*1*	*1*	*1*	*1*		*4*	*4*	*6*	*6*	*6*	*6*	*6*		*9*	*9*				
2	*1*	*1*	*1*	*1*	*1*	*4*	*4*	*4*	*6*	*6*	*6*	*6*	*6*	*9*	*9*	*9*	*9*			
3		*1*	*1*	*1*	*4*	*4*	*4*	*4*	*4*	*6*	*6*	*6*	*9*	*9*	*9*	*9*	*9*			
4			*1*		*4*	*4*	*4*	*4*	*4*		*6*		*9*	*9*	*9*	*9*	*10*	*10*	*10*	
5			*2*	*2*	*2*	*2*	*2*								*10*	*10*	*10*	*10*	*10*	
6			*2*	*2*	*2*	*2*	*2*		*5*						*10*	*10*	*10*	*10*	*10*	
7			*2*	*2*	*2*	*2*	*2*		*5*	*5*					*10*	*10*	*10*	*10*		
8					*2*	*2*	*5*	*5*	*5*	*5*			*8*	*8*	*8*	*10*	*10*	*10*		
9					*2*		*5*	*5*	*5*	*5*	*5*		*8*	*8*	*8*	*8*	*10*			
10							*5*	*5*	*5*	*5*	*5*		*8*	*8*	*8*	*8*	*8*			
11						*3*	*3*	*5*	*5*	*5*	*5*		*8*	*8*	*8*	*8*	*8*			
12					*3*	*3*	*3*							*8*	*8*	*8*	*8*			
13					*3*	*3*	*3*	*3*					*7*		*8*	*8*	*8*			
14					*3*	*3*	*3*	*3*	*3*				*7*	*7*	*8*					
15							*3*	*3*	*3*		*7*	*7*	*7*	*7*	*7*					
16							*3*	*3*	*3*		*7*	*7*	*7*	*7*	*7*					
17											*7*	*7*	*7*	*7*	*7*					

3.5.5 Relevant points of the sample test

This section exposes details about the development and an overview of the results of the sample test. For the former, specific computational aspects are provided. For the latter, the reliability of the methodology is proved.

All model instances about ACCAP and ARS were solved using AIMMS 3.12 software with LP-solver CPLEX 12.5 and a 1.7 GHz Core i3 computer in less than 25 seconds. The sample test was run for both CACCAP and DACCAP models and the general result is given in Table 34. As expected a dedicated system requires more desks than a common. So, it is more expensive, but at the same time, it is preferred by passengers (Rendeiro and Cejas, 2006).

Table 34 - Number of required desks for CACCAP and DACCAP models and Van Dijk and Van der Sluis (2006)

Time Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CACCAP	*2*	*3*	*6*	*5*	*11*	*9*	*14*	*10*	*12*	*7*	*9*	*7*	*11*	*10*	*15*	*11*	*11*	*6*	*3*	*0*
DACCAP	*2*	*3*	*7*	*6*	*12*	*11*	*16*	*12*	*13*	*8*	*10*	*6*	*13*	*12*	*17*	*13*	*12*	*5*	*3*	*0*
Van Dijk (2006)	*3*	*3*	*6*	*6*	*12*	*12*	*14*	*14*	*11*	*11*	*8*	*8*	*13*	*13*	*15*	*15*	*8*	*8*	*2*	*2*

Table 34 also presents the result obtained by Van Dijk and Van der Sluis (2006). These authors used simulation and assume hourly time intervals to develop this sample test for a dedicated system. Taking into account the number of desks by intervals of half-an-hour, Table 35 evinces the accuracy of the methodology (CACCAP and DACCAP) in order to get the minimal number of desks and to meet the service level (such as demonstrated in Section 3.5.3 and 3.5.4). Also, the maximum waiting time of twenty minutes by time interval was added to the overall service level. It is clear that the target of the three proposals (CACCAP, DACCAP and Van Dijk and Van der Sluis (2006)) is to obtain the optimal number of check-in counters assigned to flights during each time interval. However, it is important to highlight that the methodology proposed in this work is based on optimization supported by simulation, and it has the additional target of balancing the service level and his related operational cost. Meanwhile the third proposal is based on simulation and only focuses in meeting the quality of service.

Table 35 - Comparison based on the number of desks by time interval

Situation	**Allocation Policy**	**Check-in System**	**Desk by time interval (half-an-hour)**
CACCAP	*Variable*	*Common*	*162*
DACCAP	*Variable*	*Dedicated*	*181*
Van Dijk (2006)	*Variable*	*Dedicated*	*184*

The problem size of the example developed in this chapter is defined by a ten-flight-schedule. Thinking in airports with hundreds of flights per day could bring some questions about the methodology performance. For that reason, Chapter 4 presents a case study based on a busiest airport.

4. Case study – GRU airport in São Paulo, Brazil

The demand forecast for Brazilian air services expects a duplication of passengers by 2030 with regard to present levels (see Table 36). For that reason major investments have been made in the last few years and will continue in accordance with the Brazilian strategic planning from 2010 to 2030 (McKinsey and Company, 2010). The GRU Airport in São Paulo, Brazil, is the major Latin American airport in terms of volume of passengers (see Table 37), and has therefore received special attention. GRU has started in 2012 a modernization and expansion project. The project includes the reformulation of two terminals (1 and 2) and the construction of a new one (terminal 3 opened in 2014). Infrastructure investments are followed by the search for more efficient methods for using the airport resources. With this regard, the methodology developed in this thesis will help to profit the most from the recent expansion investments by increasing the airport capacity and efficiently use airport resources. Thus, the proposed methodology for the ACCAP is tested at the GRU airport. Then, Section 4.1 exposes some practical realities in airport check-in management. Section 4.2 provides parameters and assumptions needed for this case study. Section 4.3 presents the development of the case study for a common system and Section 4.4 provides general comments.

Table 36 - Demand forecast for Brazilian air service – millions passengers per year

Year	2009	2014	2020	2030
Domestic	*98*	*129*	*172*	*273*
International	*13*	*17*	*23*	*39*
Total	*111*	*146*	*195*	*312*

Source: (McKinsey and Company, 2010)

Table 37 - Major Latin American airports

Position	City Airport	Country	Annual Passengers (thousands) 2000	2010	Average annual increase 2000-2010
1	*São Paulo (Guarulhos)*	*Brazil*	*13743*	*26849*	*6.9%*
2	*Mexico DF*	*Mexico*	*21043*	*24131*	*1.4%*
3	*São Paulo (Congonhas)*	*Brazil*	*10537*	*15499*	*3.9%*
4	*Bogota*	*Colombia*	*n,a,*	*14968*	*n,a,*
5	*Brasilia*	*Brazil*	*5235*	*14347*	*10.6%*
6	*Cancun*	*Mexico*	*7745*	*12439*	*4.9%*
7	*Rio de Janeiro*	*Brazil*	*5043*	*12338*	*9.4%*

Source: (Fisher, 2011)

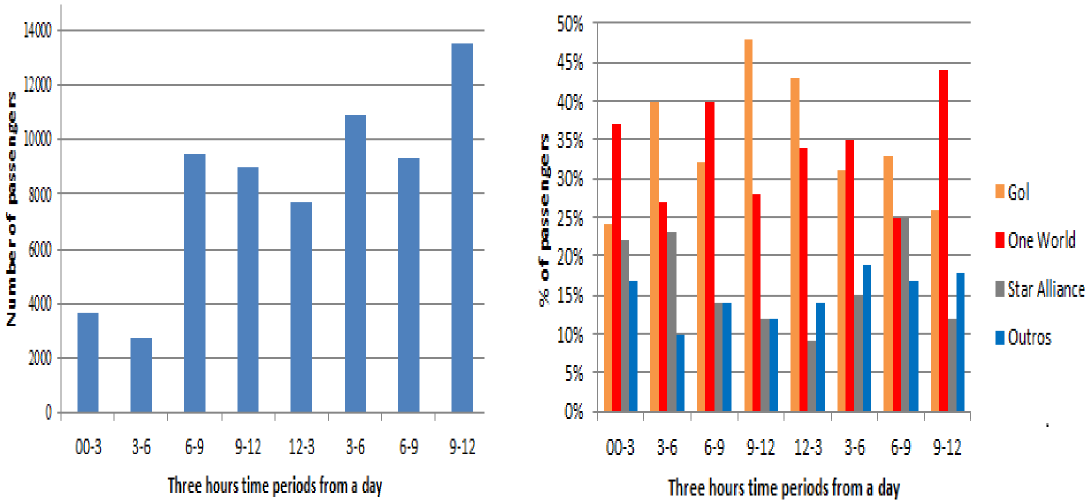
4.1. Airport reality

A real world application such as GRU is a much more complex problem than the sample test used to explain the methodology proposed in this thesis. The complexity derives from the dimension and diversity. GRU has hundreds of flights per day and flight patterns that may vary by week if not daily. Nevertheless, for a number of reasons or practical realities, the results do appear to be of interest. First, according to Van Dijk and Van der Sluis (2006), the airport check-in problem can be decomposed into smaller problems due to natural segregations such as in domestic and international flights, in airline consortia and in separate check-in areas (bays). Second, although flight patterns may vary, by optimizing representative patterns, general allocation structures and rules might be developed that perform well the minimal assignment in staffing and desks. Moreover, regarding to busiest airports, the analysis of any day as a reference is possible since they have the same level of passengers traffic every day. In other words, a busiest airport do not present seasonality in the demand. With this regard and considering the high traffic of GRU airport, the case study is developed for a specific day and for the main airline alliance operating in this airport.

Taking into account the mentioned practical realities and in order to get input data as closest to reality, Section 4.1.1 explains how to obtain the departure flight schedule. Also, Section 4.1.2 and Section 4.1.3 exposes some guidelines about the arrival pattern and check-in time, respectively.

4.1.1. Departure flight schedule (DFS)

The DFS is based upon a flight realization at GRU airport on February 2nd, 2015 and provided by the official web site (www.aeroportoguarulhos.net). It consists of the following data: flight code, airline, destination, departure time and type of the aircraft. The capacity of the airplane and the number of passengers boarded are not available. In order to get the capacity of each flight, official web site such as (www.planefinder.net) is required. Then, a table was elaborated such shown in Annex 1. In that day, 379 flights were processed and, considering a load factor of 100%, 66325 passengers could be embarked. The greater proportions of flights were evening flights and belonged to the "One World" air alliance (see Figure 8a) and Figure 8b), respectively).



a) General volume of passengers   b) Volume of passengers – by consortium

Figure 8 - Volume of passengers on February 2nd, 2015, GRU airport, São Paulo, Brazil
Source: www.aeroportoguarulhos.net and www.planefinder.net

So far, the DFS is based upon a flight realization at GRU airport on February 2nd, 2015 of "One World" alliance (see Annex 2). Now, decomposing the airport check-in problem into smaller problems considering practical realities is necessary. For this task, the following procedure determines the main clusters within the alliance:

- Step A: Compute the number of boarded passengers and the proportion of them using check-in counter service. For this task, the passenger load factor and use check-in counter factor by type of flight are required. The capacity of the flights is affected by these factors and a reference DFS is obtained.
- Step B: Sort the flights in domestic (D) and international (I).
- Step C: Within the domestic flights, sort them in two groups. The first, designated as domestic A (DA), groups the 8 busiest air domestic routes from São Paulo. The second, (DB), groups the remaining flights.
- Step D: Within the international flights, sort them in four groups. The first, designated as international A (IA), groups the flights of America (Latin and North America). The second, (IB), groups all flights except America. The

third, (IC), groups only Latin American flights. The fourth, (ID), groups all flights except Latin American.

- Step E: Establish general groups so that each of them can be assigned to a check-in bay. For this task, two points must be considered: the busiest time interval and the physical limitations of the airport building. For the former, the volume of passengers in a time interval can forecast the rough number of required desks. For example, based on sample test of Chapter 3, the busiest time interval has 216 passengers and requires 17 desks. For the latter, for busiest air terminals, the average size of check-in bays between 30 and 40 units means a real constraint. Finally, each general cluster represents a particular DFS that will be assessed independently.

The procedure given above is developed for the DFS of Annex 2 as part of this case study. Each step is detailed as follows:

- Step A: Statistical data about the load factor by continent and the use check-in counter service factor by type of flight is provided by IATA web site (www.iata.org). In addition, the National Civil Aviation Agency of Brazil (ANAC of Brazil) (www.anac.gov.br) provides the load factor of Brazilians airlines each month. Given this information (see Table 38a) and Table 38b)), the reference DFS is obtained as shown in Annex 2.

Table 38 - Passenger load factor and use check-in counter factor

a) By continent

Continent	Passenger Load factor
Asia	*76.9%*
Europe	*81.6%*
North America	*81.7%*
Middle East	*78.1%*
Latin America	*80.0%*
Africa	*67.5%*

b) By world and Brazil

	World 2014	Brazil – February 2015
Type of flight	**Use check-in counter service factor**	**Passenger Load fator**
Domestic	*70.0%*	*84.5%*
International	*90.0%*	*81.5%*

Source: IATA (2014) and ANAC (2015)

- Step B: Based on destination, the reference DFS has a column indicating the length of check-in period. Number 2 refers to domestic flights and 3 to international flights.

- Step C: The ANAC of Brazil provides the 8 air busiest domestic routes from São Paulo as shown in Table 39. The reference DFS has a column indicating the type of domestic flight (DA or DB).

Table 39 - Air busiest domestic routes from São Paulo

Destination	Passengers (thousand)
Río de Janeiro	*5681*
Brasília	*3006*
Porto Alegre	*2619*
Salvador	*2270*
Belo Horizonte	*2239*
Curitiba	*2236*
Recife	*1575*
Florianópolis	*1366*

Source: ANAC (2015)

- Step D: Based on the destination; this step can fit in two real options: the pair IA with IB or IC with ID.
- Step E: Based on the groups defined in former steps and the suggested arrival pattern for this case study (see Section 4.1.2), the key of this step is to arrange different combinations and to assess the busiest time interval of each combination as shown in Table 40. Then two groups are defined: DFS 1, containing DA, DB and IB and DFS 2 only with IA.

Table 40 - Defining the two general clusters: DFS 1 and DFS 2

		Busiest time interval of DFS 1		Busiest time interval of DFS 2	
DFS 1	**DFS 2**	**Time interval**	**Passengers**	**Time interval**	**Passengers**
Domestic	*International*	*15*	*413*	*43*	*560*
DB + IC	*DA + ID*	*14*	*388*	*43*	*691*
DB + ID	*DA + IC*	*43*	*585*	*13*	*541*
DB + IA	*DA + IB*	*43*	*485*	*42*	*386*
DB + IB	*DA + IA*	*41*	*321*	*43*	*591*
DB + DA + IB	*IA*	*42*	*465*	*43*	*394*

4.1.2. Arrival Pattern

According to Stefanik et al. (2012), an arrival pattern is influenced by a number of factors such as the volume of passengers, the integration of airport to ground transport network, the traffic city, the airport location, airport security policies and airlines procedures. Also, this topic has to do with the passengers' experience, the flight departure time, the type of flight and the passengers' provenance. For these reasons, every airport has a specific arrival pattern. In order to understand the arrival process related to a particular airport, it is necessary to collect data directly at the airport and define a set of statistical average arrival patterns (for example, with regard to a specific day and the period of the day).

For this case study, the arrival process is modeled using two arrival patterns: one for domestic flights and another for internationals. The first is provided by IATA-ADRM (2004) and the second by Chun and Mak (1999). Each of the patterns considers the time of day such shown in Table 41. Also, the international pattern is based on a study carried out in the Hong Kong Kai Tak International Airport, which by the time was the third busiest airport in the world, handling approximately 150,000 flights per year and over 75,000 passengers daily.

Table 41 - Domestic and International arrival patterns

Type of flight	**Domestic flight**			**International flight**		
	Hours of day			**Hours of day**		
Time intervals over the check-in period	**00 - 10**	**10 - 18**	**18 - 00**	**00 - 10**	**10 - 18**	**18 - 00**
210 min - 180 min				*0*	*2*	*8*
180 min - 150 min				*10*	*10*	*16*
150 min - 120 min	*0*	*0*	*4*	*20*	*26*	*34*
120 min - 90 min	*4*	*12*	*20*	*36*	*36*	*24*
90 min - 60 min	*38*	*44*	*38*	*26*	*20*	*14*
60 min - 30 min	*58*	*44*	*38*	*8*	*6*	*4*
30 min - 0 min	*0*	*0*	*0*	*0*	*0*	*0*

Source: IATA-ADRM (2004) and Chun and Mak (1999)

4.1.3. Check-in time

The check-in processing time or service rate will also depend on many factors related to the flight. Currently, two situations are relevant: one, regarding to passengers arriving for traditional check-in service, and other, only to leave the baggage. For the first, a check-in time of 2 minutes is considered (Bevilacqua, 2010 and Van Dijk and Van der Sluis, 2006). For the second, 1.5 minutes (Bruno and Genovese, 2010). According to IATA (2014) the penetration of self-service check-in is 50% for domestic and 30% for internationals flights; and the use check-in counter service is 70% and 90%, respectively. Based on that information, roughly 20% of passengers of the reference DFS use self-service check-in. Therefore, it is logical to keep the standard check-in time of 2 minutes.

4.2. Parameters and assumptions for the case study

All parameters and assumptions for this case study are detailed as follows:

- Arrivals distribution: Based on arrival pattern from Table 41.
- Departure flight schedule: based on DFS 1 and DFS 2 defined in Section 4.1.
- Length time interval: 30 minutes.
- Desk service time: 2 minutes (supported in Section 4.1).
- Desk opening cost: USD 80 per hour (Parlar and Sharafali, 2008).
- Queue cost: USD 20 per hour (Parlar and Sharafali, 2008).
- α: 10%, in accordance with the given service level.
- Check-in period: For international flights, check-in desks open three hours before the flight departure and there are 150 minutes for fulfilling the check-in process. For domestic flights, the process stars two hours before the flight departure and there are 90 minutes for fulfilling it (Diaz, 2008).
- Statistical distribution to passenger arrivals: Exponential.
- Statistical distribution for check-in time: Exponential.
- Queue configuration: bank lining.
- Queue discipline: FIFO.
- Service level: Regarding to waiting time, at least 90% of all passengers reach their check-in desk within 10 minutes and no passenger waits more than 35 minutes. Additionally, in terms of queue size, 90% of all passengers must stay inside the check-in area. For that, it is considered that at most 6 people can wait in front of each check-in desk.
- Average utilization desk: over 85%.
- Warm-up period: 60 minutes.
- Set of results: For performing each simulation experiment, a trial of twenty replications is considered because from that replications number, the average queue results are similar.
- Passengers arrive one by one. Although in many real situations passengers arrive in group, this phenomenon does not affect to a certain extent the service at the counters (Diaz, 2008).

4.3. Case study – CACCAP

In this section, the work procedure of the methodology to optimize the ACCAP is performed considering the common check-in system for each DFS. Every step involved in the methodology is explained as follows:

a) Following the Step A, the number of desks to be assigned in each time interval (B_t) is obtained and shown in Table 42 for DFS 1 and Table 43 for DFS 2.

Table 42 - Number of the required desks for CACCAP (without constraints 4.6 and 4.7), CACCAP, DACCAP (without constraints 4.13 and 4.14) and DACCAP for DFS 1

Time Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CACCAP (No 4.6–4.7)			*2*	*5*	*9*	*3*	*2*				*2*	*13*	*25*	*22*	*27*	*14*	*10*	*8*	*10*	*14*	*10*	*10*	*17*	*18*
CACCAP			*2*	*6*	*9*	*4*	*2*				*2*	*14*	*26*	*22*	*28*	*15*	*10*	*9*	*10*	*15*	*10*	*11*	*17*	*20*
DACCAP (No 4.13–4.14)			*3*	*6*	*10*	*4*	*2*				*5*	*17*	*35*	*28*	*32*	*16*	*12*	*11*	*11*	*17*	*12*	*13*	*20*	*23*
DACCAP			*3*	*6*	*10*	*4*	*2*				*5*	*17*	*35*	*28*	*32*	*16*	*12*	*11*	*11*	*17*	*12*	*13*	*20*	*23*

Time Interval	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
CACCAP (No 4.6–4.7)	*18*	*13*	*7*	*10*	*20*	*25*	*24*	*23*	*19*	*14*	*3*	*7*	*12*	*14*	*15*	*20*	*27*	*32*	*31*	*23*	*18*	*14*	*12*	*2*
CACCAP	*18*	*14*	*7*	*11*	*21*	*25*	*26*	*23*	*20*	*16*	*4*	*7*	*12*	*15*	*15*	*20*	*28*	*33*	*32*	*24*	*19*	*15*	*13*	*2*
DACCAP (No 4.13–4.14)	*21*	*15*	*8*	*12*	*24*	*29*	*30*	*26*	*22*	*16*	*4*	*9*	*14*	*17*	*17*	*23*	*32*	*40*	*39*	*29*	*24*	*15*	*13*	*2*
DACCAP	*21*	*15*	*8*	*13*	*24*	*29*	*30*	*26*	*22*	*17*	*4*	*9*	*14*	*17*	*17*	*23*	*32*	*40*	*39*	*29*	*24*	*15*	*13*	*2*

Table 43 - Number of the required desks for CACCAP (without constraints 4.6 and 4.7), CACCAP, DACCAP (without constraints 4.13 and 4.14) and DACCAP for DFS 2

Time Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CACCAP (No 4.6–4.7)	*5*	*4*	*2*		*1*	*2*	*4*	*5*	*3*	*5*	*8*	*17*	*18*	*15*	*10*	*7*	*7*	*12*	*11*	*12*	*10*	*7*	*3*	*3*
CACCAP	*5*	*4*	*2*		*1*	*3*	*5*	*5*	*3*	*5*	*9*	*17*	*19*	*17*	*11*	*8*	*8*	*12*	*12*	*12*	*11*	*7*	*4*	*3*
DACCAP (No 4.13–4.14)	*5*	*4*	*2*		*1*	*3*	*5*	*5*	*3*	*6*	*10*	*19*	*21*	*19*	*11*	*10*	*9*	*13*	*12*	*14*	*11*	*8*	*5*	*3*
DACCAP	*5*	*4*	*2*		*1*	*3*	*5*	*5*	*3*	*6*	*10*	*19*	*21*	*19*	*11*	*10*	*9*	*13*	*12*	*14*	*11*	*8*	*5*	*3*

Time Interval	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
CACCAP (No 4.6–4.7)	*3*	*4*	*7*	*8*	*5*	*5*	*6*	*9*	*9*	*8*	*8*	*9*	*6*	*7*	*8*	*10*	*15*	*25*	*27*	*19*	*15*	*8*	*4*	*3*
CACCAP	*3*	*5*	*7*	*9*	*6*	*5*	*6*	*9*	*10*	*9*	*9*	*9*	*7*	*8*	*9*	*11*	*16*	*26*	*27*	*21*	*16*	*9*	*4*	*3*
DACCAP (No 4.13–4.14)	*3*	*6*	*8*	*9*	*6*	*6*	*7*	*10*	*11*	*9*	*10*	*10*	*8*	*9*	*10*	*12*	*16*	*29*	*29*	*22*	*18*	*10*	*5*	*3*
DACCAP	*3*	*6*	*8*	*9*	*6*	*6*	*7*	*10*	*11*	*9*	*10*	*11*	*9*	*9*	*11*	*12*	*18*	*30*	*30*	*23*	*19*	*10*	*5*	*3*

b) Applying the Step B and queue theory, the main queue features in each time interval are provided in Annex 3. They evince congestion at time intervals where the utilization factor is more than or equal to one. By simulation, the main queue results and service level measures are provided for each DFS. That information is shown in Table 44 and Table 45 for DFS 1, and Table 46 and Table 47 for DFS 2. Regarding to DFS 1, the service level is not met since only 44% and 51% of the passengers reach their check-in desks within the 10 minutes and stay inside the check-in area, respectively (see Table 45). For DFS 2, those percentages are 48% and 55%, respectively (see Table 47).

Table 44 - Queue results for CACCAP model (without constraints 4.6 and 4.7) – DFS 1

Data type	**WAITING TIME**		**NUMBER WAITING**		**NUMBER OUT**
Replication	**Ave**	**Max**	**Ave**	**Max**	**Ave**
1	*7.45*	*50.54*	*63.34*	*222.00*	*8932*
2	*9.00*	*44.29*	*72.00*	*168.00*	*9127*
3	*10.88*	*38.20*	*89.77*	*172.00*	*9139*
4	*11.85*	*52.07*	*99.90*	*204.00*	*8971*
5	*12.27*	*57.18*	*104.65*	*229.00*	*9036*
6	*8.40*	*48.68*	*71.26*	*149.00*	*9099*
7	*8.26*	*37.14*	*66.00*	*151.00*	*9115*
8	*11.22*	*58.82*	*95.46*	*224.00*	*9025*
9	*19.56*	*71.59*	*166.00*	*287.00*	*9014*
10	*14.73*	*63.87*	*126.56*	*260.00*	*9065*
11	*18.76*	*90.34*	*168.00*	*444.00*	*8839*
12	*10.23*	*43.64*	*84.96*	*167.00*	*9090*
13	*13.25*	*47.78*	*108.58*	*190.00*	*9123*
14	*8.10*	*36.68*	*66.31*	*162.00*	*9084*
15	*21.48*	*73.33*	*184.17*	*326.00*	*9126*
16	*10.90*	*42.18*	*90.00*	*172.00*	*9166*
17	*19.58*	*63.54*	*160.78*	*251.00*	*8912*
18	*24.61*	*77.39*	*205.29*	*324.00*	*8988*
19	*20.13*	*72.50*	*167.80*	*302.00*	*9102*
20	*21.00*	*89.00*	*186.17*	*432.00*	*8926*
Mean	*14.08*	*57.94*	*118.85*	*241.80*	*9043.95*
Variance	*27.83*	*264.38*	*2112.88*	*7299.26*	*7752.85*
Standard deviation	*5.28*	*16.26*	*45.97*	*85.44*	*88.05*
Max	*24.61*	*90.34*	*205.29*	*444.00*	*9166.00*

Table 45 - Service level measures for CACCAP model (without constraints 4.6 and 4.7) – DFS 1

	WAITING TIME			NUMBER WAITING			
Replication	**% Pass < 10 min**	**Pass < 10 min**	**Pass > 10 min**	**% In check-in area**	**Pass In check-in area**	**Pass Out check-in area**	**Total Passengers**
1	*0.62*	*5577*	*3355*	*0.78*	*6968*	*1964*	*8932*
2	*0.67*	*6102*	*3025*	*0.72*	*6599*	*2528*	*9127*
3	*0.63*	*5798*	*3341*	*0.66*	*6028*	*3111*	*9139*
4	*0.48*	*4316*	*4655*	*0.66*	*5952*	*3019*	*8971*
5	*0.40*	*3622*	*5414*	*0.50*	*4522*	*4514*	*9036*
6	*0.72*	*6580*	*2519*	*0.78*	*7141*	*1958*	*9099*
7	*0.70*	*6419*	*2696*	*0.80*	*7262*	*1853*	*9115*
8	*0.44*	*3956*	*5069*	*0.63*	*5708*	*3317*	*9025*
9	*0.17*	*1509*	*7505*	*0.20*	*1796*	*7218*	*9014*
10	*0.37*	*3356*	*5709*	*0.50*	*4536*	*4529*	*9065*
11	*0.32*	*2854*	*5985*	*0.37*	*3251*	*5588*	*8839*
12	*0.55*	*5038*	*4052*	*0.73*	*6609*	*2481*	*9090*
13	*0.41*	*3717*	*5406*	*0.48*	*4366*	*4757*	*9123*
14	*0.80*	*7254*	*1830*	*0.82*	*7477*	*1607*	*9084*
15	*0.18*	*1637*	*7489*	*0.18*	*1680*	*7446*	*9126*
16	*0.54*	*4931*	*4235*	*0.63*	*5753*	*3413*	*9166*
17	*0.14*	*1247*	*7665*	*0.16*	*1392*	*7520*	*8912*
18	*0.14*	*1297*	*7691*	*0.16*	*1407*	*7581*	*8988*
19	*0.18*	*1613*	*7489*	*0.19*	*1758*	*7344*	*9102*
20	*0.24*	*2101*	*6825*	*0.29*	*2595*	*6331*	*8926*
TOTAL	***0.44***	***78924***	***101955***	***0.5131***	***92800***	***88079***	***180879***

Table 46 - Queue results for CACCAP model (without constraints 4.6 and 4.7) – DFS 2

Data type	**WAITING TIME**		**NUMBER WAITING**		**NUMBER OUT**
Replication	**Ave**	**Max**	**Ave**	**Max**	**Ave**
1	*21.97*	*73.75*	*100.14*	*217.00*	*5799*
2	*14.10*	*50.96*	*62.76*	*163.00*	*5835*
3	*11.05*	*51.15*	*50.19*	*146.00*	*5895*
4	*9.49*	*49.36*	*41.68*	*105.00*	*5794*
5	*15.90*	*94.92*	*77.15*	*254.00*	*5756*
6	*9.80*	*43.49*	*44.20*	*112.00*	*5933*
7	*3.38*	*19.76*	*14.70*	*94.00*	*5716*
8	*8.50*	*63.66*	*38.44*	*131.00*	*5683*
9	*14.19*	*63.81*	*63.10*	*155.00*	*5840*
10	*17.30*	*77.71*	*76.39*	*179.00*	*5833*
11	*9.87*	*61.38*	*42.95*	*139.00*	*5733*
12	*17.82*	*69.37*	*79.09*	*193.00*	*5790*
13	*24.39*	*77.24*	*110.37*	*216.00*	*5711*
14	*8.09*	*41.45*	*35.08*	*104.00*	*5666*
15	*14.42*	*61.85*	*65.23*	*203.00*	*5818*
16	*17.72*	*71.06*	*80.40*	*176.00*	*5802*
17	*3.96*	*18.52*	*17.18*	*98.00*	*5715*
18	*13.35*	*37.17*	*59.05*	*129.00*	*5810*
19	*24.68*	*87.53*	*114.14*	*253.00*	*5723*
20	*14.51*	*63.64*	*63.71*	*158.00*	*5801*
Mean	*13.72*	*58.89*	*61.80*	*161.25*	*5782.65*
Variance	*33.52*	*388.01*	*718.06*	*2326.79*	*4568.73*
Standard deviation	*5.79*	*19.70*	*26.80*	*48.24*	*67.59*
Max	*24.68*	*94.92*	*114.14*	*254.00*	*5933.00*

Table 47 - Service level measures for CACCAP model (without constraints 4.6 and 4.7) – DFS 2

Replication	WAITING TIME % Pass < 10 min	Pass < 10 min	Pass > 10 min	NUMBER WAITING % In check-in area	Pass In check-in area	Pass Out check-in area	Total Passengers
1	*0.18*	*1036*	*4763*	*0.26*	*1522*	*4277*	*5799*
2	*0.35*	*2043*	*3792*	*0.51*	*2982*	*2853*	*5835*
3	*0.52*	*3064*	*2831*	*0.64*	*3781*	*2114*	*5895*
4	*0.50*	*2924*	*2870*	*0.60*	*3491*	*2303*	*5794*
5	*0.25*	*1446*	*4310*	*0.38*	*2185*	*3571*	*5756*
6	*0.63*	*3714*	*2219*	*0.71*	*4227*	*1706*	*5933*
7	*0.95*	*5406*	*310*	*0.98*	*5591*	*125*	*5716*
8	*0.75*	*4287*	*1396*	*0.80*	*4518*	*1165*	*5683*
9	*0.61*	*3569*	*2271*	*0.56*	*3294*	*2546*	*5840*
10	*0.48*	*2814*	*3019*	*0.48*	*2828*	*3005*	*5833*
11	*0.68*	*3877*	*1856*	*0.67*	*3847*	*1886*	*5733*
12	*0.44*	*2564*	*3226*	*0.47*	*2737*	*3053*	*5790*
13	*0.16*	*913*	*4798*	*0.27*	*1527*	*4184*	*5711*
14	*0.62*	*3503*	*2163*	*0.69*	*3891*	*1775*	*5666*
15	*0.43*	*2501*	*3317*	*0.55*	*3189*	*2629*	*5818*
16	*0.22*	*1254*	*4548*	*0.37*	*2155*	*3647*	*5802*
17	*0.92*	*5282*	*433*	*0.96*	*5474*	*241*	*5715*
18	*0.39*	*2261*	*3549*	*0.44*	*2580*	*3230*	*5810*
19	*0.18*	*1036*	*4687*	*0.25*	*1412*	*4311*	*5723*
20	*0.43*	*2522*	*3279*	*0.45*	*2607*	*3194*	*5801*
TOTAL	***0.48***	***56016***	***59637***	***0.5520***	***63838***	***51815***	***115653***

c) Following the Step C and for both DFS, the utilization factors must be less than 1 to every time interval. Regarding to the fluctuation factors and considering the DFS 1, they must be more than 0.1 except to the time intervals 16, 34, 35, 44 and 47 where must be more than 0.52, 0.74, 0.21, 0.74 and 0.86, respectively. For the DFS 2, the fluctuation factors must be more than 0.1 except to the time intervals 14, 15, 44 and 46 where must be more than 0.83, 0.67, 0.70 and 0.53, respectively. These upper and lower bounds can be seen in Annex 3.

d) Applying the Step D, Table 42 and 43 show the final results for DFS 1 and DFS2, respectively. Also the main queue results and the service level measures are provided for each DFS. That information is shown in Table 48 and Table 49 for DFS 1, and Table 50 and 51 for DFS 2. Regarding to DFS 1, the overall service level is ensured since 95% and 97% of the passengers reach their check-in desks within the 10 minutes and stay inside the check-in area, respectively (see Table 49). For DFS 2, those percentages are 97% and 98%, respectively (see Table 51). Also, for both DFS, nobody waits more than 30 minutes which means an improving in the quality of service (see Table 48 for DFS 1 and Table 50 for DFS 2). At the same time, the average scheduled utilization desk over 85% is achieved (see Table 52 for DFS 1 and Table 53 for DFS 2). Finally, considering the number of passengers out of service level between Step A and Step D, 91.7% and 94.8% of reduction to waiting time and queue size, respectively, are obtained for DFS 1 (see Table 45 and Table 49). For DFS 2, those percentages are 94.18% and 96.94%, respectively (see Table 47 and Table 51).

Table 48 - Queue results for CACCAP model – DFS 1

Data type	**WAITING TIME**		**NUMBER WAITING**		**NUMBER OUT**
Replication	**Ave**	**Max**	**Ave**	**Max**	**Ave**
1	*2.38*	*24.27*	*18.61*	*79.00*	*8916*
2	*1.55*	*12.26*	*12.26*	*80.00*	*9001*
3	*1.97*	*11.25*	*15.75*	*70.00*	*9103*
4	*2.87*	*14.40*	*22.69*	*80.00*	*9026*
5	*2.84*	*29.07*	*23.11*	*98.00*	*9049*
6	*2.05*	*29.80*	*16.91*	*81.00*	*9069*
7	*1.39*	*14.34*	*10.92*	*57.00*	*8962*
8	*4.44*	*25.37*	*35.72*	*93.00*	*9173*
9	*3.41*	*22.88*	*27.43*	*115.00*	*9145*
10	*1.77*	*16.19*	*13.98*	*94.00*	*9015*
11	*2.74*	*16.81*	*21.44*	*95.00*	*8934*
12	*2.57*	*14.39*	*20.33*	*84.00*	*9034*
13	*1.85*	*9.44*	*14.74*	*74.00*	*9074*
14	*1.15*	*16.58*	*9.00*	*71.00*	*8901*
15	*2.22*	*12.10*	*17.80*	*112.00*	*9157*
16	*4.50*	*28.48*	*36.56*	*108.00*	*9173*
17	*3.16*	*21.53*	*24.67*	*109.00*	*8908*
18	*4.86*	*28.37*	*38.81*	*148.00*	*9103*
19	*2.49*	*14.00*	*19.85*	*72.00*	*9074*
20	*1.78*	*9.12*	*14.12*	*73.00*	*9047*
Mean	*2.60*	*18.53*	*20.74*	*89.65*	*9043.20*
Variance	*1.04*	*46.55*	*67.84*	*421.33*	*7146.36*
Standard deviation	*1.02*	*6.82*	*8.24*	*20.53*	*84.54*
Max	*4.86*	*29.80*	*38.81*	*148.00*	*9173.00*

Table 49 - Service level measures of CACCAP model – DFS 1

Replication	WAITING TIME			NUMBER WAITING			Total Passengers
	% Pass < 10 min	Pass < 10 min	Pass > 10 min	% In check-in area	Pass In check-in area	Pass Out check-in area	
1	*0.98*	*8726*	*190*	*0.98*	*8774*	*142*	*8916*
2	*0.99*	*8907*	*94*	*1.00*	*8973*	*28*	*9001*
3	*1.00*	*9092*	*11*	*1.00*	*9103*	*0*	*9103*
4	*0.95*	*8585*	*441*	*0.98*	*8825*	*201*	*9026*
5	*0.93*	*8431*	*618*	*0.97*	*8776*	*273*	*9049*
6	*0.99*	*8968*	*101*	*1.00*	*9069*	*0*	*9069*
7	*0.99*	*8876*	*86*	*1.00*	*8951*	*11*	*8962*
8	*0.90*	*8274*	*899*	*0.95*	*8705*	*468*	*9173*
9	*0.89*	*8156*	*989*	*0.94*	*8571*	*574*	*9145*
10	*0.97*	*8785*	*230*	*0.98*	*8853*	*162*	*9015*
11	*0.94*	*8355*	*579*	*0.97*	*8680*	*254*	*8934*
12	*0.96*	*8696*	*338*	*0.98*	*8873*	*161*	*9034*
13	*1.00*	*9074*	*0*	*1.00*	*9074*	*0*	*9074*
14	*0.99*	*8856*	*45*	*1.00*	*8879*	*22*	*8901*
15	*0.98*	*9007*	*150*	*1.00*	*9147*	*10*	*9157*
16	*0.86*	*7910*	*1263*	*0.91*	*8377*	*796*	*9173*
17	*0.89*	*7940*	*968*	*0.94*	*8392*	*516*	*8908*
18	*0.88*	*7992*	*1111*	*0.91*	*8249*	*854*	*9103*
19	*0.96*	*8741*	*333*	*0.99*	*8976*	*98*	*9074*
20	*1.00*	*9047*	*0*	*1.00*	*9047*	*0*	*9047*
TOTAL	***0.95***	***172418***	***8446***	***0.9747***	***176294***	***4570***	***180864***

Table 50 - Queue results for CACCAP model – DFS 2

Data type	WAITING TIME		NUMBER WAITING		NUMBER OUT
Replication	**Ave**	**Max**	**Ave**	**Max**	**Ave**
1	*1.19*	*7.47*	*5.19*	*42.00*	*5744*
2	*1.31*	*9.12*	*5.74*	*42.00*	*5788*
3	*2.31*	*22.57*	*10.34*	*62.00*	*5829*
4	*1.24*	*11.51*	*5.37*	*44.00*	*5711*
5	*3.04*	*27.07*	*13.77*	*61.00*	*5881*
6	*1.32*	*14.06*	*5.86*	*36.00*	*5843*
7	*1.89*	*23.93*	*8.23*	*65.00*	*5701*
8	*2.14*	*16.90*	*9.32*	*47.00*	*5749*
9	*1.63*	*15.22*	*7.17*	*44.00*	*5778*
10	*1.64*	*13.21*	*7.12*	*36.00*	*5733*
11	*1.81*	*11.05*	*7.79*	*70.00*	*5679*
12	*2.52*	*29.13*	*11.01*	*68.00*	*5768*
13	*3.68*	*21.65*	*16.19*	*65.00*	*5803*
14	*1.15*	*12.40*	*4.86*	*32.00*	*5598*
15	*1.36*	*9.51*	*5.99*	*44.00*	*5814*
16	*2.18*	*15.97*	*9.70*	*46.00*	*5874*
17	*3.12*	*14.80*	*13.66*	*66.00*	*5774*
18	*2.60*	*26.79*	*11.41*	*93.00*	*5753*
19	*3.17*	*14.69*	*14.06*	*66.00*	*5846*
20	*2.17*	*23.07*	*9.78*	*59.00*	*5762*
Mean	*2.07*	*17.01*	*9.13*	*54.40*	*5771.40*
Variance	*0.54*	*40.75*	*10.88*	*223.54*	*4503.14*
Standard deviation	*0.74*	*6.38*	*3.30*	*14.95*	*67.11*
Max	*3.68*	*29.13*	*16.19*	*93.00*	*5881.00*

Table 51 - Service level measures of the CACCAP model – DFS 2

Replication	WAITING TIME			NUMBER WAITING			
	% Pass < 10 min	Pass < 10 min	Pass > 10 min	% In check-in area	Pass In check-in area	Pass Out check-in area	Total Passengers
1	*1.00*	*5744*	*0*	*1.00*	*5744*	*0*	*5744*
2	*1.00*	*5788*	*0*	*1.00*	*5788*	*0*	*5788*
3	*0.96*	*5622*	*207*	*0.98*	*5691*	*138*	*5829*
4	*1.00*	*5695*	*16*	*1.00*	*5711*	*0*	*5711*
5	*0.95*	*5603*	*278*	*0.96*	*5669*	*212*	*5881*
6	*1.00*	*5830*	*13*	*1.00*	*5843*	*0*	*5843*
7	*0.97*	*5533*	*168*	*0.99*	*5638*	*63*	*5701*
8	*0.95*	*5477*	*272*	*0.97*	*5596*	*153*	*5749*
9	*0.98*	*5657*	*121*	*0.99*	*5721*	*57*	*5778*
10	*0.99*	*5684*	*49*	*1.00*	*5722*	*11*	*5733*
11	*0.99*	*5649*	*30*	*1.00*	*5679*	*0*	*5679*
12	*0.95*	*5461*	*307*	*0.95*	*5483*	*285*	*5768*
13	*0.92*	*5351*	*452*	*0.97*	*5637*	*166*	*5803*
14	*1.00*	*5593*	*5*	*1.00*	*5598*	*0*	*5598*
15	*1.00*	*5814*	*0*	*1.00*	*5814*	*0*	*5814*
16	*0.99*	*5831*	*43*	*1.00*	*5853*	*21*	*5874*
17	*0.88*	*5058*	*716*	*0.98*	*5636*	*138*	*5774*
18	*0.95*	*5468*	*285*	*0.96*	*5551*	*202*	*5753*
19	*0.95*	*5554*	*292*	*0.99*	*5780*	*66*	*5846*
20	*0.96*	*5544*	*218*	*0.99*	*5691*	*71*	*5762*
TOTAL	***0.97***	***111956***	***3472***	***0.9863***	***113845***	***1583***	***115428***

Table 52 - Average Scheduled Utilization of check-in counters – CACCAP – DFS 1

Atendente	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Scheduled Utilization	*0.97*	*0.96*	*0.97*	*0.97*	*0.97*	*0.97*	*0.97*	*0.97*	*0.96*	*0.95*	*0.95*	*0.95*	*0.94*	*0.94*	*0.94*	*0.94*	*0.94*

Atendente	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Scheduled Utilization	*0.93*	*0.93*	*0.93*	*0.93*	*0.92*	*0.93*	*0.92*	*0.95*	*0.95*	*0.97*	*0.96*	*0.93*	*0.91*	*0.91*	*0.9*	*0.99*

Table 53 - Average Scheduled Utilization of check-in counters – CACCAP – DFS 2

Atendente	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scheduled Utilization	*0.95*	*0.95*	*0.92*	*0.93*	*0.92*	*0.93*	*0.92*	*0.91*	*0.91*	*0.93*	*0.92*	*0.93*	*0.94*	*0.94*

Atendente	15	16	17	18	19	20	21	22	23	24	25	26	27
Scheduled Utilization	*0.92*	*0.91*	*0.9*	*0.91*	*0.91*	*0.89*	*0.86*	*0.85*	*0.86*	*0.85*	*0.85*	*0.85*	*0.85*

4.4. Relevant points of the case study

This section exposes details about the development and an overview of the results of the case study. For the former, specific computational aspects are provided. For the latter, important inferences are provided.

All model instances about ACCAP were solved using AIMMS 3.12 software with LP-solver CPLEX 12.5 and a 1.7 GHz Core i3 computer in less than 25 seconds. With regard to the adjacent resource scheduling model instances, computational times between 5 and 10 minutes were obtained. Both DFS 1 and DFS 2 were run for CACCAP and DACCAP models and the results are given in Tables 42 and 43. The detailed DACCAP outcomes and their related adjacent resource scheduling are provided in Annex 3. Based on the results of this case study, the following statements are inferred:

- The number of required desks for both DFS 1 and DFS 2 obtained by IATA procedure is given in Table 54. As explained in Chapter 2, these results are mainly for tactical and strategic planning, but at the same time, they represent the bounds for practical implementation. Comparing these results with the ones obtained through the new methodology (see Table 55) one realizes its accuracy as they are within or closest the range of values suggested by IATA.

Table 54 - Number of check-in counters for DFS 1 and DFS 2 based on IATA suggestions

	DFS 1 – Number of Check-in Desk		DFS 2 – Number of Check-in Desk	
Maximum Queuing Time	**CACCAP**	**DACCAP**	**CACCAP**	**DACCAP**
10 minutes	*32*	*44*	*26*	*36*
30 minutes	*22*	*30*	*17*	*23*

Table 55 - Maximum number of required desks by the methodology and IATA

	CACCAP	IATA	DACCAP	IATA
Maximum number of desks - DFS 1	*33*	*32*	*40*	*44*
Maximum number of desks - DFS 2	*27*	*26*	*30*	*36*

- Regarding the quality of service, the results or CACCAP meet the overall service level (see from Table 48 to Table 51). Moreover, considering the average scheduled utilization desk over 85%, no more than 30 minutes of waiting time is achieved in each time interval.
- The utilization and fluctuation factors constraints have more impact in the common system than in the dedicated one. In fact, queue theory seems more applicable for check-in analysis when common system is applied. As several flights may check-in at the same set of counters, the collective arrival pattern will generally show less fluctuation than the arrival pattern of individual flights. As concluded from CACCAP results, establishing the utilization factor less than 1 and finding the right fluctuation factor for each time interval is mandatory in order to balance the service level and his related operative cost.
- For this case study, the utilization and fluctuation factors constraints have not impact in the dedicated system. For each type of flight, the utilization factor is usually less than one and the number of passengers per time interval is fewer than in a common system (see Annex 3). These reasons can lead to explain the similarity of results between the model with and without the utilization and fluctuation factors constraints (see Tables 42 and 43). Also, the simulation experiments by type of flight ensure only the overall service level (Annex 3) and improving the service level in each time interval can mean an overuse the resources (average scheduled utilization desk less than 85%). Finally, as expected, the dedicated check-in system requires more desks than the common check-in (see Tables 42 and 43).

5. Conclusions

This dissertation proposes a new methodology to optimize the Airport Check-in Counter Allocation Problem by minimizing operational costs such that a given service is ensured. It promotes the combination of optimization and simulation techniques to face real world applications. Furthermore, it is proposed two new optimization models that include constraints regarding to the utilization factor concept of queue theory, and the fluctuation in passenger arrival rate. The first model is applied for a common system while the second for a dedicated one.

First, the methodology was tested with a real sample test available in the literature. Based on the result of the sample test and considering real constraints, the half an hour represents a right length of the time interval to discretize the airport check-in problem. Also, a comparison between our proposal and another based only on simulation evinces the reliability and accuracy of the methodology in order to reach the trade-off between the operational costs and a given service level. For the latter, the service level is meet in the whole time window and improved in each time interval (maximum waiting time of twenty minutes).

Second, the methodology is tested with a real world airport application that is more complex in terms of volume of passengers and number of flights. The case study was developed for a specific day and for the main airline alliance operating in the GRU airport. The analysis of any day as a reference is possible since busiest airports have the same level of passengers traffic every day or they do not present seasonality in the demand. To start, the airport check-in problem is decomposed into smaller problems considering natural separations such as domestic and international flights or airline consortia. Each general group represents a particular departure flight schedule that is assessed independently. The results evince reliability and accuracy of the methodology in order to balance the service level and his related operative costs. Regarding to operative costs, the results point to the feasibility of the proposed methodology since they fit in the suggested range by IATA. For the service level, it is met in the whole time window and improved in each time interval (maximum waiting time of thirty minutes).

Based on the results of the examples developed in this work, the utilization and fluctuation factors constraints have more impact in the common than dedicated model. Thereby, queue theory seems more applicable for check-in analysis when common system is applied. Furthermore, the propagation problems to closest immediate intervals could appear when there is a decrease in the passenger arrival rate between two adjacent time intervals. With this regard the optimization models were strengthened with the fluctuation factor constraints in order to counteract that problem. That remark derives from the goal rule of queue theory: it is better to prevent lines before they are formed. Regarding to dedicated systems, it is important to note that only in the sample test, some flights were affected by the fluctuation factor constraints. This situation can be explained by two issues. The first has to do with the use of an instructive arrival pattern while the case study uses a real one. The second because of the sample test did not consider load factor of passengers and use check-in counter service factor.

Another relevant point is that the methodology proposed in this work is based on optimization supported by simulation, and it has the additional target of balancing the service level and his related operational cost. Meanwhile the most proposals in the literature are based on simulation and only focus in the service level. Furthermore, the new methodology can be developed easily because optimization and simulation are widely available Operational Research tools.

This work will serve to assess and improve the existing management check-in system of airports. Each airport represents a particular situation and this methodology gives flexibility for fitting in any scenario. Different options such as common or dedicated check-in systems and different features such as arrival pattern, service level, check-in time, time interval length and cost of the airport resources, let this methodology to be useful in the ACCAP task. Also, regarding to dedicated check-in systems, it is possible to distinguish two types of arrangements: by flight and by airline. The former is based on a flight and the latter in a group of flights of the same company. Both types of arrangements are perfectly suited in the proposed methodology.

However, in spite of existing reference manuals for the air transport sector which provide statistical data and suggests values for check-in features such as arrival pattern, service level, check-in time and cost of the airport resources, these features are inherent and particular for every airport. Thereby, further research is required in order to identify these characteristics for a specific scenario. Moreover, regarding to this work, future directions of research are identified and detailed as follows:

- Strengthen the ACCAP with operation models for workforce planning in order to consider practical realities of staff scheduling for check-in systems.
- Extend the analysis of the ACCAP taking into account more complex optimization approach such as stochastic, robust and management risk.
- Identify the impact of the passenger load factor in the ACCAP performing a sensitivity analyses of this parameter.
- Deepen the check-in process study considering an operational capacity relationship between the check-in counter facility and the baggage management facility.
- It is clear that the proposed methodology focuses on the Airport Check-in Counter Allocation Problem (ACCAP) at a strategic level. However, in order to fit it in a tactical approach, it is necessary to set allocation patterns for each instance of a planning season. For an operational approach, it is necessary to extend the analysis of the ACCAP considering different queue disciplines such as the distinction among passengers in business and economic class.

Finally, this work promotes the combination of Linear Programming and Simulation as an Operational Research technique to optimize general planning and scheduling problems. This technique can be useful in other application areas such as: call centers, manufacturing, transportation, health service and administrative logistics.

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Annex 1: Departure flight schedule – GRU Airport – February 2th, 2015

	Code	Airline	Destination	Departure time	Aircraft	Capacity
1	*AD 2898*	*Azul*	*(CGB) Cuiaba*	*12:05 a.m.*	*Embraer 195*	*130*
2	*AD 5086*	*Azul*	*(IOS) Ilheus*	*12:15 a.m.*	*Embraer 195*	*130*
3	*EK 262*	*Emirates*	*(DXB) Dubai*	*01:20 a.m.*	*Boeing 777-300*	*360*
4	*G3 1844*	*Gol*	*(MCZ) Maceio*	*12:01 a.m.*	*Boeing 737-800*	*180*
5	*G3 2078*	*Gol*	*(JDO) Juazeiro Do Norte*	*12:30 a.m.*	*Boeing 737-700*	*150*
6	*G3 9290*	*Gol*	*(MAO) Manaus*	*12:30 a.m.*	*Boeing 737-800*	*180*
7	*G3 2166*	*Gol*	*(BPS) Porto Seguro*	*12:40 a.m.*	*Boeing 737-800*	*180*
8	*G3 7726*	*Gol*	*(SDQ) Santo Domingo*	*01:25 a.m.*	*Boeing 737-800*	*180*
9	*UA 860*	*United Airlines*	*(IAD) Washington*	*12:05 p.m.*	*Boeing 777-200*	*260*
10	*SA 225*	*South African Airways*	*(JNB) Johannesburg*	*12:35 a.m.*	*A340-300*	*250*
11	*AV 248*	*AVIANCA*	*(BOG) Bogota*	*02:20 a.m.*	*A319*	*130*
12	*CM 758*	*Copa Airlines*	*(PTY) Panama City*	*02:28 a.m.*	*Boeing 737-800*	*180*
13	*JJ 3350*	*TAM Linhas Aereas*	*(NAT) Natal*	*12:05 a.m.*	*A320*	*150*
14	*JJ 3557*	*TAM Linhas Aereas*	*(IGU) Iguassu Falls*	*12:05 a.m.*	*A319*	*130*
15	*AA 216*	*American Airlines*	*(LAX) Los Angeles*	*12:15 a.m.*	*Boeing 777-200*	*260*
16	*JJ 3322*	*TAM Linhas Aereas*	*(FOR) Fortaleza*	*12:15 a.m.*	*A321*	*180*
17	*JJ 3816*	*TAM Linhas Aereas*	*(SSA) Salvador*	*12:30 a.m.*	*A320*	*150*
18	*JJ 8110*	*TAM Linhas Aereas*	*(MCO) Orlando*	*12:43 a.m.*	*Boeing 767-300*	*200*
19	*AA 930*	*American Airlines*	*(MIA) Miami*	*02:01 a.m.*	*Boeing 777-300*	*300*
20	*JJ 3646*	*TAM Linhas Aereas*	*(REC) Recife*	*03:05 a.m.*	*A321*	*180*
21	*QR 772*	*Qatar Airways*	*(DOH) Doha*	*04:15 a.m.*	*Boeing 777-200*	*260*
22	*LA 2764*	*LAN Airlines*	*(LIM) Lima*	*05:10 a.m.*	*A320*	*150*
23	*JJ 8044*	*TAM Linhas Aereas*	*(MVD) Montevideo*	*05:40 a.m.*	*A320*	*150*
24	*G3 2034*	*Gol*	*(FOR) Fortaleza*	*05:00 a.m.*	*Boeing 737-800*	*180*
25	*G3 2060*	*Gol*	*(SSA) Salvador*	*05:10 a.m.*	*Boeing 737-800*	*180*
26	*G3 2138*	*Gol*	*(REC) Recife*	*05:25 a.m.*	*Boeing 737-800*	*180*
27	*G3 1700*	*Gol*	*(SDU) Rio De Janeiro*	*05:50 a.m.*	*Boeing 737-800*	*180*
28	*G3 2178*	*Gol*	*(VIX) Vitoria*	*05:50 a.m.*	*Boeing 737-800*	*180*
29	*G3 1920*	*Gol*	*(CWB) Curitiba*	*05:50 a.m.*	*Boeing 737-800*	*180*
30	*CM 702*	*Copa Airlines*	*(PTY) Panama City*	*04:16 a.m.*	*Boeing 737-800*	*180*
31	*O6 6376*	*Avianca Brazil*	*(JDO) Juazeiro Do Norte*	*05:00 a.m.*	*A318*	*120*
32	*TK 16*	*Turkish Airlines*	*(IST) Istanbul*	*05:15 a.m.*	*Boeing 777-300*	*330*
33	*AD 5133*	*Azul*	*(SDU) Rio De Janeiro*	*05:55 a.m.*	*Embraer 190*	*110*
34	*OB 733*	*BoA*	*(CBB) Cochabamba*	*04:30 a.m.*	*Boeing 737-300*	*150*
35	*AD 5018*	*Azul*	*(BSB) Brasilia*	*06:05 a.m.*	*Embraer 195*	*130*
36	*AD 5005*	*Azul*	*(POA) Porto Alegre*	*06:10 a.m.*	*Embraer 195*	*130*
37	*AD 2860*	*Azul*	*(VIX) Vitoria*	*06:20 a.m.*	*Embraer 195*	*130*
38	*AD 2410*	*Azul*	*(CNF) Belo Horizonte*	*06:35 a.m.*	*Embraer 195*	*130*
39	*AD 6957*	*Azul*	*(CWB) Curitiba*	*06:40 a.m.*	*Embraer 195*	*130*
40	*AD 2584*	*Azul*	*(NVT) Navegantes*	*07:25 a.m.*	*Embraer 195*	*130*
41	*AD 2400*	*Azul*	*(SDU) Rio De Janeiro*	*08:25 a.m.*	*Embraer 195*	*130*
42	*AD 5186*	*Azul*	*(POA) Porto Alegre*	*08:40 a.m.*	*Embraer 195*	*130*
43	*AD 2482*	*Azul*	*(PLU) Belo Horizonte*	*08:45 a.m.*	*Embraer 195*	*130*
44	*H2 601*	*Sky Airline*	*(SCL) Santiago*	*08:20 a.m.*	*A319*	*130*
45	*G3 2199*	*Gol*	*(SSA) Salvador*	*06:05 a.m.*	*Boeing 737-800*	*180*
46	*G3 1770*	*Gol*	*(BPS) Porto Seguro*	*06:20 a.m.*	*Boeing 737-800*	*180*
47	*G3 1740*	*Gol*	*(GIG) Rio De Janeiro*	*06:35 a.m.*	*Boeing 737-800*	*180*
48	*G3 1850*	*Gol*	*(POA) Porto Alegre*	*06:40 a.m.*	*Boeing 737-800*	*180*
49	*G3 1160*	*Gol*	*(SSA) Salvador*	*06:45 a.m.*	*Boeing 737-800*	*180*
50	*G3 1260*	*Gol*	*(FLN) Florianopolis*	*06:45 a.m.*	*Boeing 737-800*	*180*
51	*G3 1680*	*Gol*	*(BSB) Brasilia*	*06:55 a.m.*	*Boeing 737-800*	*180*
52	*G3 9005*	*Gol*	*(REC) Recife*	*07:00 a.m.*	*Boeing 737-800*	*180*
53	*G3 1341*	*Gol*	*(VIX) Vitoria*	*07:05 a.m.*	*Boeing 737-800*	*180*

	Code	Airline	Destination	Departure time	Aircraft	Capacity
54	*G3 1890*	*Gol*	*(CGR) Campo Grande*	*07:25 a.m.*	*Boeing 737-800*	*180*
55	*G3 2002*	*Gol*	*(SDU) Rio De Janeiro*	*07:50 a.m.*	*Boeing 737-800*	*180*
56	*G3 1780*	*Gol*	*(GYN) Goiania*	*07:50 a.m.*	*Boeing 737-800*	*180*
57	*G3 1262*	*Gol*	*(FLN) Florianopolis*	*07:50 a.m.*	*Boeing 737-800*	*180*
58	*G3 2022*	*Gol*	*(CNF) Belo Horizonte*	*08:00 a.m.*	*Boeing 737-800*	*180*
59	*G3 1922*	*Gol*	*(CWB) Curitiba*	*08:20 a.m.*	*Boeing 737-800*	*180*
60	*G3 1365*	*Gol*	*(GIG) Rio De Janeiro*	*08:30 a.m.*	*Boeing 737-700*	*150*
61	*G3 2004*	*Gol*	*(SDU) Rio De Janeiro*	*08:50 a.m.*	*Boeing 737-700*	*150*
62	*O6 6312*	*Avianca Brazil*	*(SSA) Salvador*	*06:10 a.m.*	*A320*	*150*
63	*O6 6380*	*Avianca Brazil*	*(CGB) Cuiaba*	*06:10 a.m.*	*Fokker 100*	*120*
64	*CM 724*	*Copa Airlines*	*(PTY) Panama City*	*06:16 a.m.*	*Boeing 737-800*	*180*
65	*O6 6304*	*Avianca Brazil*	*(REC) Recife*	*06:35 a.m.*	*A320*	*150*
66	*O6 6372*	*Avianca Brazil*	*(FOR) Fortaleza*	*06:55 a.m.*	*A320*	*150*
67	*TA 916*	*TACA*	*(LIM) Lima*	*07:10 a.m.*	*A321*	*180*
68	*O6 6362*	*Avianca Brazil*	*(GYN) Goiania*	*07:30 a.m.*	*A318*	*110*
69	*O6 6126*	*Avianca Brazil*	*(POA) Porto Alegre*	*07:35 a.m.*	*Fokker 100*	*120*
70	*O6 6250*	*Avianca Brazil*	*(SSA) Salvador*	*07:40 a.m.*	*A320*	*150*
71	*JJ 3524*	*TAM Linhas Aereas*	*(REC) Recife*	*06:56 a.m.*	*A321*	*180*
72	*JJ 3157*	*TAM Linhas Aereas*	*(CWB) Curitiba*	*06:55 a.m.*	*A320*	*150*
73	*JJ 3306*	*TAM Linhas Aereas*	*(NAT) Natal*	*07:09 a.m.*	*A321*	*180*
74	*JJ 3686*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*07:07 a.m.*	*A320*	*150*
75	*JJ 8026*	*TAM Linhas Aereas*	*(SCL) Santiago*	*7:35 AM*	*Boeing 777-300*	*360*
76	*JJ 3896*	*TAM Linhas Aereas*	*(SSA) Salvador*	*07:23 a.m.*	*A321*	*180*
77	*JJ 8125*	*TAM Linhas Aereas*	*(ASU) Asuncion*	*07:40 a.m.*	*A320*	*150*
78	*JJ 3614*	*TAM Linhas Aereas*	*(CGR) Campo Grande*	*08:06 a.m.*	*A320*	*150*
79	*JJ 3299*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*07:50 a.m.*	*A320*	*150*
80	*JJ 3466*	*TAM Linhas Aereas*	*(GYN) Goiania*	*07:55 a.m.*	*A320*	*150*
81	*JJ 8000*	*TAM Linhas Aereas*	*(EZE) Buenos Aires*	*07:55 a.m.*	*A330-200*	*250*
82	*JJ 3684*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*08:05 a.m.*	*A320*	*150*
83	*JJ 8014*	*TAM Linhas Aereas*	*(AEP) Buenos Aires*	*08:12 a.m.*	*A320*	*150*
84	*JJ 3415*	*TAM Linhas Aereas*	*(FLN) Florianopolis*	*8:05 AM*	*A320*	*150*
85	*JJ 3490*	*TAM Linhas Aereas*	*(LDB) Londrina*	*08:10 a.m.*	*A320*	*150*
86	*JJ 3344*	*TAM Linhas Aereas*	*(CNF) Belo Horizonte*	*08:20 a.m.*	*A321*	*180*
87	*JJ 3362*	*TAM Linhas Aereas*	*(VIX) Vitoria*	*08:25 a.m.*	*A320*	*150*
88	*JJ 3562*	*TAM Linhas Aereas*	*(BSB) Brasilia*	*08:39 a.m.*	*A321*	*180*
89	*JJ 8046*	*TAM Linhas Aereas*	*(MVD) Montevideo*	*08:39 a.m.*	*A320*	*150*
90	*JJ 8130*	*TAM Linhas Aereas*	*(ROS) Rosario*	*09:02 a.m.*	*A320*	*150*
91	*JJ 3504*	*TAM Linhas Aereas*	*(REC) Recife*	*08:42 a.m.*	*A321*	*180*
92	*JJ 8066*	*TAM Linhas Aereas*	*(LIM) Lima*	*08:55 a.m.*	*Boeing 767-300*	*200*
93	*LA 757*	*LAN Airlines*	*(SCL) Santiago*	*9:15 AM*	*A319*	*130*
94	*JJ 3289*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*09:12 a.m.*	*A321*	*180*
95	*JJ 3748*	*TAM Linhas Aereas*	*(MAO) Manaus*	*09:30 a.m.*	*Boeing 767-300*	*200*
96	*JJ 3302*	*TAM Linhas Aereas*	*(FOR) Fortaleza*	*09:43 a.m.*	*A321*	*180*
97	*JJ 8094*	*TAM Linhas Aereas*	*(MIA) Miami*	*10:31 a.m.*	*Boeing 777-300*	*360*
98	*JJ 8086*	*TAM Linhas Aereas*	*(MCO) Orlando*	*10:45 AM*	*Boeing 767-300*	*200*
99	*JJ 3804*	*TAM Linhas Aereas*	*(SSA) Salvador*	*10:35 a.m.*	*A320*	*150*
100	*JJ 3554*	*TAM Linhas Aereas*	*(BEL) Belem*	*10:48 AM*	*A320*	*150*
101	*JJ 3320*	*TAM Linhas Aereas*	*(SLZ) Sao Luiz*	*10:50 a.m.*	*A320*	*150*
102	*AA 234*	*American Airlines*	*(MIA) Miami*	*11:40 a.m.*	*Boeing 777-300*	*300*
103	*JJ 3664*	*TAM Linhas Aereas*	*(AJU) Aracaju*	*11:03 a.m.*	*A320*	*150*
104	*JJ 3310*	*TAM Linhas Aereas*	*(NAT) Natal*	*11:16 a.m.*	*A321*	*180*
105	*JJ 3356*	*TAM Linhas Aereas*	*(JPA) Joao Pessoa*	*11:34 a.m.*	*A320*	*150*
106	*AD 6923*	*Azul*	*(CNF) Belo Horizonte*	*09:05 a.m.*	*Embraer 195*	*130*
107	*AD 2700*	*Azul*	*(REC) Recife*	*09:25 a.m.*	*Embraer 195*	*130*
108	*AD 2412*	*Azul*	*(CNF) Belo Horizonte*	*09:55 a.m.*	*Embraer 190*	*110*
109	*AD 4960*	*Azul*	*(GYN) Goiania*	*09:55 a.m.*	*Embraer 195*	*130*
110	*AD 2604*	*Azul*	*(CGB) Cuiaba*	*10:20 a.m.*	*Embraer 195*	*130*
111	*AD 2402*	*Azul*	*(SDU) Rio De Janeiro*	*10:25 a.m.*	*Embraer 190*	*110*
112	*AD 9207*	*Azul*	*(CWB) Curitiba*	*10:35 a.m.*	*Embraer 190*	*110*

Code	Airline	Destination	Departure time	Aircraft	Capacity	Code
113	*AD 2861*	*Azul*	*(POA) Porto Alegre*	*11:05 a.m.*	*Embraer 195*	*130*
114	*AR 2241*	*Aerolineas Argentinas*	*(AEP) Buenos Aires*	*11:54 a.m.*	*Embraer 190*	*110*
115	*G3 7680*	*Gol*	*(AEP) Buenos Aires*	*09:15 a.m.*	*Boeing 737-800*	*180*
116	*G3 1872*	*Gol*	*(CGB) Cuiaba*	*09:20 a.m.*	*Boeing 737-800*	*180*
117	*G3 2082*	*Gol*	*(BSB) Brasilia*	*09:20 a.m.*	*Boeing 737-700*	*150*
118	*G3 1162*	*Gol*	*(SSA) Salvador*	*09:35 a.m.*	*Boeing 737-800*	*180*
119	*G3 1282*	*Gol*	*(REC) Recife*	*09:40 a.m.*	*Boeing 737-800*	*180*
120	*G3 1822*	*Gol*	*(FOR) Fortaleza*	*09:45 a.m.*	*Boeing 737-800*	*180*
121	*G3 2006*	*Gol*	*(CNF) Belo Horizonte*	*09:50 a.m.*	*Boeing 737-700*	*150*
122	*G3 1650*	*Gol*	*(MAO) Manaus*	*09:55 a.m.*	*Boeing 737-800*	*180*
123	*G3 1840*	*Gol*	*(MCZ) Maceio*	*10:10 a.m.*	*Boeing 737-800*	*180*
124	*G3 1590*	*Gol*	*(BEL) Belem*	*10:20 a.m.*	*Boeing 737-700*	*150*
125	*G3 7660*	*Gol*	*(SCL) Santiago*	*10:25 a.m.*	*Boeing 737-800*	*180*
126	*G3 7630*	*Gol*	*(MVD) Montevideo*	*10:25 a.m.*	*Boeing 737-800*	*180*
127	*G3 1240*	*Gol*	*(NAT) Natal*	*10:30 a.m.*	*Boeing 737-800*	*180*
128	*G3 1180*	*Gol*	*(REC) Recife*	*10:30 a.m.*	*Boeing 737-800*	*180*
129	*G3 1706*	*Gol*	*(SDU) Rio De Janeiro*	*10:35 a.m.*	*Boeing 737-800*	*180*
130	*G3 1350*	*Gol*	*(AJU) Aracaju*	*10:35 a.m.*	*Boeing 737-800*	*180*
131	*G3 1684*	*Gol*	*(BSB) Brasilia*	*10:50 a.m.*	*Boeing 737-700*	*150*
132	*G3 1924*	*Gol*	*(CWB) Curitiba*	*11:00 a.m.*	*Boeing 737-800*	*180*
133	*G3 1854*	*Gol*	*(POA) Porto Alegre*	*11:05 a.m.*	*Boeing 737-800*	*180*
134	*G3 7600*	*Gol*	*(VVI) Santa Cruz*	*11:05 a.m.*	*Boeing 737-800*	*180*
135	*G3 1380*	*Gol*	*(IGU) Iguassu Falls*	*11:10 a.m.*	*Boeing 737-800*	*180*
136	*G3 7624*	*Gol*	*(CCS) Caracas*	*11:15 a.m.*	*Boeing 737-800*	*180*
137	*G3 7450*	*Gol*	*(EZE) Buenos Aires*	*11:20 a.m.*	*Boeing 737-800*	*180*
138	*G3 2044*	*Gol*	*(GIG) Rio De Janeiro*	*11:25 a.m.*	*Boeing 737-700*	*150*
139	*G3 1806*	*Gol*	*(CNF) Belo Horizonte*	*11:55 a.m.*	*Boeing 737-700*	*150*
140	*O6 6319*	*Avianca Brazil*	*(BSB) Brasilia*	*09:10 a.m.*	*A320*	*150*
141	*AV 86*	*AVIANCA*	*(BOG) Bogota*	*09:47 a.m.*	*A330-200*	*250*
142	*O6 6356*	*Avianca Brazil*	*(SSA) Salvador*	*10:05 a.m.*	*A320*	*150*
143	*O6 6174*	*Avianca Brazil*	*(FLN) Florianopolis*	*10:55 a.m.*	*A318*	*110*
144	*O6 6390*	*Avianca Brazil*	*(FOR) Fortaleza*	*11:20 a.m.*	*A320*	*150*
145	*O6 6324*	*Avianca Brazil*	*(REC) Recife*	*11:30 a.m.*	*A320*	*150*
146	*O6 6252*	*Avianca Brazil*	*(GIG) Rio De Janeiro*	*11:55 a.m.*	*A320*	*150*
147	*AD 5110*	*Azul*	*(CGR) Campo Grande*	*12:05 p.m.*	*Embraer 195*	*130*
148	*AD 5019*	*Azul*	*(POA) Porto Alegre*	*12:35 p.m.*	*Embraer 195*	*130*
149	*AD 2858*	*Azul*	*(VIX) Vitoria*	*12:55 p.m.*	*Embraer 190*	*110*
150	*AD 6925*	*Azul*	*(SDU) Rio De Janeiro*	*01:50 p.m.*	*Embraer 190*	*110*
151	*AD 2466*	*Azul*	*(CWB) Curitiba*	*01:55 p.m.*	*Embraer 195*	*130*
152	*AD 5187*	*Azul*	*(CNF) Belo Horizonte*	*02:00 p.m.*	*Embraer 195*	*130*
153	*AD 4962*	*Azul*	*(GYN) Goiania*	*02:00 p.m.*	*Embraer 190*	*110*
154	*AD 2486*	*Azul*	*(PLU) Belo Horizonte*	*02:20 p.m.*	*ATR 72*	*80*
155	*AD 4206*	*Azul*	*(SSA) Salvador*	*02:45 p.m.*	*Embraer 195*	*130*
156	*G3 1164*	*Gol*	*(SSA) Salvador*	*12:10 p.m.*	*Boeing 737-800*	*180*
157	*G3 1982*	*Gol*	*(VIX) Vitoria*	*12:35 p.m.*	*Boeing 737-800*	*180*
158	*G3 2064*	*Gol*	*(FLN) Florianopolis*	*12:40 p.m.*	*Boeing 737-800*	*180*
159	*G3 1900*	*Gol*	*(FOR) Fortaleza*	*12:40 p.m.*	*Boeing 737-800*	*180*
160	*G3 7480*	*Gol*	*(ASU) Asuncion*	*01:00 p.m.*	*Boeing 737-800*	*180*
161	*G3 2026*	*Gol*	*(POA) Porto Alegre*	*01:20 p.m.*	*Boeing 737-800*	*180*
162	*G3 7682*	*Gol*	*(AEP) Buenos Aires*	*01:20 p.m.*	*Boeing 737-800*	*180*
163	*G3 1732*	*Gol*	*(NVT) Navegantes*	*01:25 p.m.*	*Boeing 737-700*	*150*
164	*G3 2074*	*Gol*	*(CGB) Cuiaba*	*01:40 p.m.*	*Boeing 737-800*	*180*
165	*G3 1782*	*Gol*	*(GYN) Goiania*	*01:50 p.m.*	*Boeing 737-800*	*180*
166	*G3 1190*	*Gol*	*(LDB) Londrina*	*01:55 p.m.*	*Boeing 737-800*	*180*
167	*G3 1824*	*Gol*	*(FOR) Fortaleza*	*02:00 p.m.*	*Boeing 737-800*	*180*
168	*G3 1266*	*Gol*	*(FLN) Florianopolis*	*02:05 p.m.*	*Boeing 737-800*	*180*
169	*G3 2036*	*Gol*	*(CWB) Curitiba*	*02:15 p.m.*	*Boeing 737-800*	*180*
170	*G3 1686*	*Gol*	*(BSB) Brasilia*	*02:15 p.m.*	*Boeing 737-800*	*180*
171	*G3 1744*	*Gol*	*(GIG) Rio De Janeiro*	*02:30 p.m.*	*Boeing 737-800*	*180*

Code	Airline	Destination	Departure time	Aircraft	Capacity	Code
172	*G3 1342*	*Gol*	*(UDI) Uberlandia*	*02:35 p.m.*	*Boeing 737-700*	*150*
173	*G3 1984*	*Gol*	*(VIX) Vitoria*	*02:50 p.m.*	*Boeing 737-700*	*150*
174	*G3 1247*	*Gol*	*(CNF) Belo Horizonte*	*02:55 p.m.*	*Boeing 737-700*	*150*
175	*O6 6122*	*Avianca Brazil*	*(POA) Porto Alegre*	*12:35 p.m.*	*Fokker 100*	*120*
176	*O6 6178*	*Avianca Brazil*	*(PFB) Passo Fundo*	*01:05 p.m.*	*Fokker 100*	*120*
177	*O6 6314*	*Avianca Brazil*	*(SSA) Salvador*	*01:10 p.m.*	*A320*	*150*
178	*CM 700*	*Copa Airlines*	*(PTY) Panama City*	*01:02 p.m.*	*Boeing 737-800*	*180*
179	*O6 6290*	*Avianca Brazil*	*(GYN) Goiania*	*02:10 p.m.*	*Fokker 100*	*120*
180	*LA 4541*	*LAN Airlines*	*(EZE) Buenos Aires*	*12:15 p.m.*	*A320*	*150*
181	*JJ 8010*	*TAM Linhas Aereas*	*(AEP) Buenos Aires*	*12:15 p.m.*	*A320*	*150*
182	*JJ 3494*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*12:19 p.m.*	*A319*	*130*
183	*JJ 3154*	*TAM Linhas Aereas*	*(SSA) Salvador*	*12:25 p.m.*	*A321*	*180*
184	*JJ 3329*	*TAM Linhas Aereas*	*(CWB) Curitiba*	*12:33 p.m.*	*A320*	*150*
185	*JJ 9772*	*TAM Linhas Aereas*	*(SCL) Santiago*	*12:44 p.m.*	*A320*	*150*
186	*JJ 3582*	*TAM Linhas Aereas*	*(BSB) Brasilia*	*12:50 p.m.*	*A320*	*150*
187	*JJ 3636*	*TAM Linhas Aereas*	*(MCZ) Maceio*	*01:00 p.m.*	*A321*	*180*
188	*JJ 3878*	*TAM Linhas Aereas*	*(FOR) Fortaleza*	*12:57 p.m.*	*A321*	*180*
189	*JJ 3559*	*TAM Linhas Aereas*	*(IGU) Iguassu Falls*	*01:20 p.m.*	*A320*	*150*
190	*JJ 3355*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*01:27 p.m.*	*A320*	*150*
191	*JJ 3360*	*TAM Linhas Aereas*	*(CNF) Belo Horizonte*	*01:32 p.m.*	*A320*	*150*
192	*JJ 3692*	*TAM Linhas Aereas*	*(REC) Recife*	*01:40 p.m.*	*A320*	*150*
193	*JJ 3530*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*01:50 p.m.*	*A320*	*150*
194	*PZ 707*	*TAM*	*(AGT) Ciudad del Este*	*02:05 p.m.*	*A320*	*150*
195	*JJ 3579*	*TAM Linhas Aereas*	*(BSB) Brasilia*	*02:20 p.m.*	*A320*	*150*
196	*JJ 3293*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*02:23 p.m.*	*A320*	*150*
197	*AD 2404*	*Azul*	*(SDU) Rio De Janeiro*	*03:05 p.m.*	*Embraer 195*	*130*
198	*OB 739*	*BoA*	*(VVI) Santa Cruz*	*03:25 p.m.*	*Boeing 737-300*	*150*
199	*AD 5022*	*Azul*	*(BSB) Brasilia*	*03:45 p.m.*	*Embraer 195*	*130*
200	*AD 6929*	*Azul*	*(SDU) Rio De Janeiro*	*04:15 p.m.*	*Embraer 190*	*110*
201	*AD 5007*	*Azul*	*(POA) Porto Alegre*	*04:20 p.m.*	*Embraer 195*	*130*
202	*AD 5016*	*Azul*	*(SDU) Rio De Janeiro*	*05:10 p.m.*	*Embraer 195*	*130*
203	*AD 2862*	*Azul*	*(VIX) Vitoria*	*05:40 p.m.*	*Embraer 195*	*130*
204	*H2 603*	*Sky Airline*	*(SCL) Santiago*	*05:55 p.m.*	*A319*	*130*
205	*UX 58*	*Air Europa*	*(MAD) Madrid*	*04:05 p.m.*	*A330-200*	*250*
206	*AZ 675*	*Alitalia*	*(FCO) Rome*	*07:00 p.m.*	*Boeing 777-200*	*300*
207	*EQ 518*	*TAME*	*(LIM) Lima*	*04:50 p.m.*	*Embraer 170*	*80*
208	*DT 746*	*TAAG*	*(LAD) Luanda*	*04:45 p.m.*	*Boeing 777-300*	*360*
209	*G3 1708*	*Gol*	*(SDU) Rio De Janeiro*	*03:15 p.m.*	*Boeing 737-800*	*180*
210	*G3 1166*	*Gol*	*(SSA) Salvador*	*03:20 p.m.*	*Boeing 737-800*	*180*
211	*G3 1748*	*Gol*	*(GIG) Rio De Janeiro*	*03:20 p.m.*	*Boeing 737-700*	*150*
212	*G3 1382*	*Gol*	*(IGU) Iguassu Falls*	*03:35 p.m.*	*Boeing 737-700*	*150*
213	*G3 2091*	*Gol*	*(THE) Teresina*	*03:45 p.m.*	*Boeing 737-800*	*180*
214	*G3 1772*	*Gol*	*(BPS) Porto Seguro*	*03:50 p.m.*	*Boeing 737-800*	*180*
215	*G3 1928*	*Gol*	*(CWB) Curitiba*	*04:00 p.m.*	*Boeing 737-700*	*150*
216	*G3 2086*	*Gol*	*(REC) Recife*	*04:05 p.m.*	*Boeing 737-800*	*180*
217	*G3 2088*	*Gol*	*(BSB) Brasilia*	*04:20 p.m.*	*Boeing 737-800*	*180*
218	*G3 7730*	*Gol*	*(PUJ) Punta Cana*	*04:30 p.m.*	*Boeing 737-800*	*180*
219	*G3 2010*	*Gol*	*(SDU) Rio De Janeiro*	*04:35 p.m.*	*Boeing 737-800*	*180*
220	*G3 1858*	*Gol*	*(POA) Porto Alegre*	*04:35 p.m.*	*Boeing 737-800*	*180*
221	*G3 1810*	*Gol*	*(CNF) Belo Horizonte*	*05:05 p.m.*	*Boeing 737-800*	*180*
222	*G3 2056*	*Gol*	*(CGB) Cuiaba*	*04:55 p.m.*	*Boeing 737-700*	*150*
223	*G3 1746*	*Gol*	*(GIG) Rio De Janeiro*	*05:10 p.m.*	*Boeing 737-800*	*180*
224	*G3 1168*	*Gol*	*(SSA) Salvador*	*05:15 p.m.*	*Boeing 737-800*	*180*
225	*G3 1242*	*Gol*	*(NAT) Natal*	*05:15 p.m.*	*Boeing 737-800*	*180*
226	*G3 1842*	*Gol*	*(MCZ) Maceio*	*05:25 p.m.*	*Boeing 737-800*	*180*
227	*G3 2198*	*Gol*	*(BPS) Porto Seguro*	*05:30 p.m.*	*Boeing 737-800*	*180*
228	*G3 1784*	*Gol*	*(GYN) Goiania*	*05:40 p.m.*	*Boeing 737-800*	*180*
229	*O6 6378*	*Avianca Brazil*	*(FOR) Fortaleza*	*03:15 p.m.*	*A318*	*110*
230	*LX 2695*	*SWISS*	*(ZRH) Zurich*	*03:54 p.m.*	*A340-300*	*250*

Code	Airline	Destination	Departure time	Aircraft	Capacity	Code
231	*O6 6350*	*Avianca Brazil*	*(NAT) Natal*	*03:45 p.m.*	*A320*	*150*
232	*O6 6302*	*Avianca Brazil*	*(REC) Recife*	*04:15 p.m.*	*A320*	*150*
233	*O6 6260*	*Avianca Brazil*	*(FLN) Florianopolis*	*04:40 p.m.*	*A320*	*150*
234	*O6 6188*	*Avianca Brazil*	*(BSB) Brasilia*	*04:45 p.m.*	*A320*	*150*
235	*O6 6128*	*Avianca Brazil*	*(POA) Porto Alegre*	*05:20 p.m.*	*Fokker 100*	*120*
236	*O6 6386*	*Avianca Brazil*	*(CGB) Cuiaba*	*05:35 p.m.*	*Fokker 100*	*120*
237	*TP 82*	*TAP Portugal*	*(LIS) Lisbon*	*05:45 p.m.*	*A340-300*	*250*
238	*O6 6310*	*Avianca Brazil*	*(SSA) Salvador*	*05:45 p.m.*	*A320*	*150*
239	*JJ 3331*	*TAM Linhas Aereas*	*(CWB) Curitiba*	*3:22 PM*	*A320*	*150*
240	*JJ 3894*	*TAM Linhas Aereas*	*(SSA) Salvador*	*03:28 p.m.*	*A321*	*180*
241	*JJ 3376*	*TAM Linhas Aereas*	*(VIX) Vitoria*	*03:30 p.m.*	*A320*	*150*
242	*LA 3506*	*LAN Airlines*	*(BOG) Bogota*	*3:50 PM*	*Boeing 767-300*	*200*
243	*JJ 3612*	*TAM Linhas Aereas*	*(BPS) Porto Seguro*	*3:55 PM*	*A320*	*150*
244	*JJ 3185*	*TAM Linhas Aereas*	*(FLN) Florianopolis*	*03:40 p.m.*	*A320*	*150*
245	*LA 751*	*LAN Airlines*	*(SCL) Santiago*	*03:56 p.m.*	*Boeing 787-8*	*250*
246	*JJ 3548*	*TAM Linhas Aereas*	*(REC) Recife*	*04:05 p.m.*	*A321*	*180*
247	*JJ 3492*	*TAM Linhas Aereas*	*(RAO) Ribeirao Preto*	*04:05 p.m.*	*A319*	*130*
248	*JJ 3592*	*TAM Linhas Aereas*	*(CGR) Campo Grande*	*04:25 p.m.*	*A320*	*150*
249	*JJ 3546*	*TAM Linhas Aereas*	*(GYN) Goiania*	*04:30 p.m.*	*A320*	*150*
250	*JJ 3507*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*04:38 p.m.*	*A321*	*180*
251	*JJ 3876*	*TAM Linhas Aereas*	*(CGB) Cuiaba*	*04:50 p.m.*	*A320*	*150*
252	*IB 6824*	*Iberia*	*(MAD) Madrid*	*04:57 p.m.*	*A340-600*	*350*
253	*JJ 3337*	*TAM Linhas Aereas*	*(CWB) Curitiba*	*05:05 p.m.*	*A320*	*150*
254	*JJ 3396*	*TAM Linhas Aereas*	*(LDB) Londrina*	*05:15 p.m.*	*A320*	*150*
255	*LA 753*	*LAN Airlines*	*(SCL) Santiago*	*5:30 PM*	*Boeing 767-300*	*250*
256	*JJ 3516*	*TAM Linhas Aereas*	*(REC) Recife*	*05:31 p.m.*	*A320*	*150*
257	*JJ 3326*	*TAM Linhas Aereas*	*(CNF) Belo Horizonte*	*05:30 p.m.*	*A320*	*150*
258	*PZ 722*	*TAM*	*(EZE) Buenos Aires*	*05:28 p.m.*	*A320*	*150*
259	*JJ 3113*	*TAM Linhas Aereas*	*(FLN) Florianopolis*	*05:40 p.m.*	*A320*	*150*
260	*JJ 3510*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*05:45 p.m.*	*A320*	*150*
261	*BA 246*	*British Airways*	*(LHR) London*	*06:01 p.m.*	*Boeing 747-400*	*300*
262	*LA 761*	*LAN Airlines*	*(SCL) Santiago*	*7:00 PM*	*A320*	*150*
263	*QR 771*	*Qatar Airways*	*(EZE) Buenos Aires*	*06:50 p.m.*	*Boeing 777-200*	*260*
264	*JJ 3386*	*TAM Linhas Aereas*	*(BEL) Belem*	*06:55 p.m.*	*A320*	*150*
265	*JJ 8008*	*TAM Linhas Aereas*	*(AEP) Buenos Aires*	*07:39 p.m.*	*A320*	*150*
266	*JJ 3668*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*07:33 p.m.*	*A319*	*130*
267	*JJ 3555*	*TAM Linhas Aereas*	*(CWB) Curitiba*	*8:10 PM*	*A320*	*150*
268	*JJ 3849*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*07:45 p.m.*	*A320*	*150*
269	*JJ 3498*	*TAM Linhas Aereas*	*(REC) Recife*	*07:44 p.m.*	*A321*	*180*
270	*JJ 3178*	*TAM Linhas Aereas*	*(SSA) Salvador*	*08:00 p.m.*	*A321*	*180*
271	*JJ 3750*	*TAM Linhas Aereas*	*(MAO) Manaus*	*08:05 p.m.*	*A321*	*180*
272	*LA 2766*	*LAN Airlines*	*(LIM) Lima*	*08:25 p.m.*	*Boeing 767-300*	*200*
273	*JJ 8028*	*TAM Linhas Aereas*	*(SCL) Santiago*	*8:50 PM*	*A320*	*150*
274	*G3 2066*	*Gol*	*(VIX) Vitoria*	*06:15 p.m.*	*Boeing 737-700*	*150*
275	*G3 2012*	*Gol*	*(SDU) Rio De Janeiro*	*06:20 p.m.*	*Boeing 737-800*	*180*
276	*G3 1750*	*Gol*	*(GIG) Rio De Janeiro*	*06:35 p.m.*	*Boeing 737-800*	*180*
277	*G3 1860*	*Gol*	*(POA) Porto Alegre*	*06:40 p.m.*	*Boeing 737-800*	*180*
278	*G3 1288*	*Gol*	*(REC) Recife*	*06:40 p.m.*	*Boeing 737-800*	*180*
279	*G3 2014*	*Gol*	*(SDU) Rio De Janeiro*	*06:50 p.m.*	*Boeing 737-800*	*180*
280	*G3 1469*	*Gol*	*(BEL) Belem*	*07:15 p.m.*	*Boeing 737-800*	*180*
281	*G3 7684*	*Gol*	*(AEP) Buenos Aires*	*07:25 p.m.*	*Boeing 737-800*	*180*
282	*G3 1559*	*Gol*	*(GIG) Rio De Janeiro*	*07:35 p.m.*	*Boeing 737-700*	*150*
283	*G3 1828*	*Gol*	*(FOR) Fortaleza*	*07:55 p.m.*	*Boeing 737-800*	*180*
284	*G3 2080*	*Gol*	*(FLN) Florianopolis*	*07:55 p.m.*	*Boeing 737-700*	*150*
285	*G3 1716*	*Gol*	*(SDU) Rio De Janeiro*	*08:05 p.m.*	*Boeing 737-800*	*180*
286	*G3 2054*	*Gol*	*(NAT) Natal*	*08:05 p.m.*	*Boeing 737-800*	*180*
287	*G3 1290*	*Gol*	*(REC) Recife*	*08:05 p.m.*	*Boeing 737-800*	*180*
288	*G3 2076*	*Gol*	*(GYN) Goiania*	*08:10 p.m.*	*Boeing 737-800*	*180*
289	*G3 2092*	*Gol*	*(BSB) Brasilia*	*08:20 p.m.*	*Boeing 737-700*	*150*

Code	Airline	Destination	Departure time	Aircraft	Capacity	Code
290	*G3 1652*	*Gol*	*(MAO) Manaus*	*08:35 p.m.*	*Boeing 737-800*	*180*
291	*G3 7662*	*Gol*	*(SCL) Santiago*	*08:55 p.m.*	*Boeing 737-800*	*180*
292	*O6 6152*	*Avianca Brazil*	*(GIG) Rio De Janeiro*	*06:20 p.m.*	*A318*	*110*
293	*SA 223*	*South African Airways*	*(JNB) Johannesburg*	*06:30 p.m.*	*A330-200*	*250*
294	*SQ 67*	*Singapore Airlines*	*(BCN) Barcelona*	*06:53 p.m.*	*Boeing 777-300*	*300*
295	*LH 505*	*Lufthansa*	*(MUC) Munich*	*06:49 p.m.*	*A340-600*	*300*
296	*O6 6364*	*Avianca Brazil*	*(MCZ) Maceio*	*07:30 p.m.*	*A320*	*150*
297	*LH 507*	*Lufthansa*	*(FRA) Frankfurt*	*07:49 p.m.*	*Boeing 747-8*	*350*
298	*O6 6316*	*Avianca Brazil*	*(REC) Recife*	*07:55 p.m.*	*A320*	*150*
299	*TK 15*	*Turkish Airlines*	*(EZE) Buenos Aires*	*7:25 PM*	*Boeing 777-300*	*300*
300	*O6 6370*	*Avianca Brazil*	*(FOR) Fortaleza*	*08:25 p.m.*	*A320*	*150*
301	*LX 93*	*SWISS*	*(ZRH) Zurich*	*08:36 p.m.*	*A340-300*	*250*
302	*AD 5015*	*Azul*	*(BSB) Brasilia*	*06:20 p.m.*	*Embraer 195*	*130*
303	*AD 2488*	*Azul*	*(PLU) Belo Horizonte*	*06:25 p.m.*	*ATR 72*	*80*
304	*AD 2480*	*Azul*	*(CGB) Cuiaba*	*06:35 p.m.*	*Embraer 195*	*130*
305	*AD 2514*	*Azul*	*(NVT) Navegantes*	*06:35 p.m.*	*Embraer 195*	*130*
306	*AD 2416*	*Azul*	*(CNF) Belo Horizonte*	*06:50 p.m.*	*Embraer 195*	*130*
307	*AD 4964*	*Azul*	*(GYN) Goiania*	*06:55 p.m.*	*Embraer 190*	*110*
308	*AD 2406*	*Azul*	*(SDU) Rio De Janeiro*	*07:10 p.m.*	*Embraer 190*	*110*
309	*AD 4158*	*Azul*	*(CGR) Campo Grande*	*07:25 p.m.*	*Embraer 195*	*130*
310	*AD 5023*	*Azul*	*(POA) Porto Alegre*	*08:30 p.m.*	*Embraer 190*	*110*
311	*AD 2880*	*Azul*	*(BSB) Brasilia*	*08:50 p.m.*	*Embraer 195*	*130*
312	*AF 457*	*Air France*	*(CDG) Paris*	*06:08 p.m.*	*Boeing 777-300*	*300*
313	*AR 2245*	*Aerolineas Argentinas*	*(AEP) Buenos Aires*	*08:40 p.m.*	*Embraer 190*	*110*
314	*G3 2032*	*Gol*	*(MGF) Maringa*	*09:05 p.m.*	*Boeing 737-700*	*150*
315	*G3 1736*	*Gol*	*(NVT) Navegantes*	*09:05 p.m.*	*Boeing 737-700*	*150*
316	*G3 1814*	*Gol*	*(CNF) Belo Horizonte*	*09:15 p.m.*	*Boeing 737-800*	*180*
317	*G3 1718*	*Gol*	*(SDU) Rio De Janeiro*	*09:25 p.m.*	*Boeing 737-800*	*180*
318	*G3 1692*	*Gol*	*(BSB) Brasilia*	*09:25 p.m.*	*Boeing 737-800*	*180*
319	*G3 7452*	*Gol*	*(EZE) Buenos Aires*	*09:30 p.m.*	*Boeing 737-800*	*180*
320	*G3 1862*	*Gol*	*(POA) Porto Alegre*	*09:45 p.m.*	*Boeing 737-800*	*180*
321	*G3 1272*	*Gol*	*(FLN) Florianopolis*	*09:55 p.m.*	*Boeing 737-700*	*150*
322	*G3 7468*	*Gol*	*(ROS) Rosario*	*10:00 p.m.*	*Boeing 737-800*	*180*
323	*G3 1172*	*Gol*	*(SSA) Salvador*	*10:05 p.m.*	*Boeing 737-800*	*180*
324	*G3 7632*	*Gol*	*(MVD) Montevideo*	*10:15 p.m.*	*Boeing 737-800*	*180*
325	*G3 1932*	*Gol*	*(CWB) Curitiba*	*10:20 p.m.*	*Boeing 737-800*	*180*
326	*G3 2098*	*Gol*	*(BEL) Belem*	*10:30 p.m.*	*Boeing 737-800*	*180*
327	*G3 1352*	*Gol*	*(AJU) Aracaju*	*10:45 p.m.*	*Boeing 737-800*	*180*
328	*G3 2070*	*Gol*	*(CGB) Cuiaba*	*11:10 p.m.*	*Boeing 737-800*	*180*
329	*G3 1182*	*Gol*	*(JPA) Joao Pessoa*	*11:25 p.m.*	*Boeing 737-800*	*180*
330	*G3 1902*	*Gol*	*(SLZ) Sao Luiz*	*11:40 p.m.*	*Boeing 737-800*	*180*
331	*G3 1384*	*Gol*	*(IGU) Iguassu Falls*	*11:40 p.m.*	*Boeing 737-800*	*180*
332	*G3 7610*	*Gol*	*(COR) Cordoba*	*11:45 p.m.*	*Boeing 737-800*	*180*
333	*G3 1292*	*Gol*	*(REC) Recife*	*11:45 p.m.*	*Boeing 737-800*	*180*
334	*O6 6258*	*Avianca Brazil*	*(SSA) Salvador*	*09:30 p.m.*	*A320*	*150*
335	*O6 6318*	*Avianca Brazil*	*(FLN) Florianopolis*	*09:45 p.m.*	*A320*	*150*
336	*TP 84*	*TAP Portugal*	*(LIS) Lisbon*	*10:19 p.m.*	*A330-200*	*250*
337	*AC 91*	*Air Canada*	*(YYZ) Toronto*	*10:36 PM*	*Boeing 777-200*	*260*
338	*UA 30*	*United Airlines*	*(EWR) Newark*	*11:00 PM*	*Boeing 767-400*	*250*
339	*UA 844*	*United Airlines*	*(ORD) Chicago*	*11:00 p.m.*	*Boeing 777-200*	*260*
340	*UA 978*	*United Airlines*	*(IAH) Houston*	*11:30 PM*	*Boeing 777-200*	*260*
341	*KL 792*	*KLM*	*(AMS) Amsterdam*	*09:01 p.m.*	*Boeing 777-300*	*425*
342	*AF 459*	*Air France*	*(CDG) Paris*	*09:25 p.m.*	*Boeing 777-200*	*250*
343	*DL 472*	*Delta Air Lines*	*(JFK) New York*	*9:03 PM*	*Boeing 767-400*	*250*
344	*DL 104*	*Delta Air Lines*	*(ATL) Atlanta*	*10:41 PM*	*Boeing 767-300*	*200*
345	*DL 52*	*Delta Air Lines*	*(DTW) Detroit*	*11:24 PM*	*Boeing 767-300*	*200*
346	*DL 58*	*Delta Air Lines*	*(ATL) Atlanta*	*11:28 PM*	*Boeing 767-400*	*250*
347	*AM 15*	*Aeromexico*	*(MEX) Mexico City*	*11:55 p.m.*	*Boeing 777-200*	*260*
348	*AD 2701*	*Azul*	*(CWB) Curitiba*	*09:20 p.m.*	*Embraer 195*	*130*

Code	Airline	Destination	Departure time	Aircraft	Capacity	Code
349	*AD 2418*	*Azul*	*(CNF) Belo Horizonte*	*09:20 p.m.*	*Embraer 190*	*110*
350	*AD 6908*	*Azul*	*(SSA) Salvador*	*09:50 p.m.*	*Embraer 195*	*130*
351	*EY 190*	*Etihad Airways*	*(AUH) Abu Dhabi*	*11:40 p.m.*	*A340-500*	*250*
352	*JJ 3630*	*TAM Linhas Aereas*	*(CGB) Cuiaba*	*09:35 p.m.*	*A320*	*150*
353	*JJ 8106*	*TAM Linhas Aereas*	*(COR) Cordoba*	*09:40 p.m.*	*A320*	*150*
354	*JJ 8030*	*TAM Linhas Aereas*	*(MVD) Montevideo*	*09:45 p.m.*	*A320*	*150*
355	*JJ 3398*	*TAM Linhas Aereas*	*(SSA) Salvador*	*09:50 p.m.*	*A320*	*150*
356	*JJ 3316*	*TAM Linhas Aereas*	*(NAT) Natal*	*10:05 p.m.*	*A320*	*150*
357	*JJ 8070*	*TAM Linhas Aereas*	*(FRA) Frankfurt*	*10:10 p.m.*	*Boeing 777-300*	*360*
358	*JJ 3180*	*TAM Linhas Aereas*	*(BSB) Brasilia*	*10:15 p.m.*	*A320*	*150*
359	*JJ 8062*	*TAM Linhas Aereas*	*(MXP) Milan*	*10:20 p.m.*	*A330*	*250*
360	*JJ 3335*	*TAM Linhas Aereas*	*(CWB) Curitiba*	*10:25 p.m.*	*A320*	*150*
361	*JJ 3295*	*TAM Linhas Aereas*	*(POA) Porto Alegre*	*10:25 p.m.*	*A321*	*180*
362	*JJ 8017*	*TAM Linhas Aereas*	*(ASU) Asuncion*	*10:25 p.m.*	*A320*	*150*
363	*JJ 3442*	*TAM Linhas Aereas*	*(CNF) Belo Horizonte*	*10:35 p.m.*	*A320*	*150*
364	*JJ 8108*	*TAM Linhas Aereas*	*(CDG) Paris*	*10:35 p.m.*	*Boeing 777-300*	*360*
365	*JJ 3443*	*TAM Linhas Aereas*	*(GIG) Rio De Janeiro*	*10:35 p.m.*	*A320*	*150*
366	*AA 906*	*American Airlines*	*(MIA) Miami*	*10:40 PM*	*Boeing 777-300*	*300*
367	*JJ 8064*	*TAM Linhas Aereas*	*(MAD) Madrid*	*10:40 p.m.*	*Boeing 767-300*	*200*
368	*JJ 8080*	*TAM Linhas Aereas*	*(JFK) New York*	*11:05 PM*	*A330*	*250*
369	*AA 950*	*American Airlines*	*(JFK) New York*	*11:10 PM*	*Boeing 777-300*	*300*
370	*JJ 3666*	*TAM Linhas Aereas*	*(THE) Teresina*	*11:15 p.m.*	*A320*	*150*
371	*JJ 3358*	*TAM Linhas Aereas*	*(JPA) Joao Pessoa*	*11:20 p.m.*	*A320*	*150*
372	*JJ 3159*	*TAM Linhas Aereas*	*(FLN) Florianopolis*	*11:20 p.m.*	*A320*	*150*
373	*JJ 3644*	*TAM Linhas Aereas*	*(MCZ) Maceio*	*11:25 p.m.*	*A321*	*180*
374	*JJ 8090*	*TAM Linhas Aereas*	*(MIA) Miami*	*11:40 PM*	*Boeing 777-300*	*360*
375	*JJ 8112*	*TAM Linhas Aereas*	*(MEX) Mexico City*	*11:40 PM*	*A330*	*250*
376	*AA 962*	*American Airlines*	*(DFW) Dallas*	*11:40 PM*	*Boeing 777-300*	*300*
377	*JJ 8084*	*TAM Linhas Aereas*	*(LHR) London*	*11:45 p.m.*	*Boeing 777-300*	*360*
378	*JJ 8102*	*TAM Linhas Aereas*	*(JFK) New York*	*12:05 AM*	*Boeing 767-300*	*200*
379	*JJ 3506*	*TAM Linhas Aereas*	*(REC) Recife*	*11:55 p.m.*	*A321*	*180*

Annex 2: Departure flight schedule – GRU Airport – February 2th, 2015 – Reference – One World

	Code	Airline	Destination	Departure time	Check-in period	Domestic	International	Passengers
1	JJ 3350	TAM Linhas Aereas	(NAT) Natal	12:05 a.m.	2	DB		89
2	JJ 3557	TAM Linhas Aereas	(IGU) Iguassu Falls	12:05 a.m.	2	DB		77
3	AA 216	American Airlines	(LAX) Los Angeles	12:15 a.m.	3		IA	192
4	JJ 3322	TAM Linhas Aereas	(FOR) Fortaleza	12:15 a.m.	2	DB		108
5	JJ 3816	TAM Linhas Aereas	(SSA) Salvador	12:30 a.m.	2	DA		89
6	JJ 8110	TAM Linhas Aereas	(MCO) Orlando	12:43 a.m.	3		IA	147
7	AA 930	American Airlines	(MIA) Miami	02:01 a.m.	3		IA	222
8	JJ 3646	TAM Linhas Aereas	(REC) Recife	03:05 a.m.	2	DA		108
9	QR 772	Qatar Airways	(DOH) Doha	04:15 a.m.	3		IB	184
10	LA 2764	LAN Airlines	(LIM) Lima	05:10 a.m.	3		IA	111
11	JJ 8044	TAM Linhas Aereas	(MVD) Montevideo	05:40 a.m.	3		IA	111
12	JJ 3524	TAM Linhas Aereas	(REC) Recife	06:56 a.m.	2	DA		108
13	JJ 3157	TAM Linhas Aereas	(CWB) Curitiba	06:55 a.m.	2	DA		89
14	JJ 3306	TAM Linhas Aereas	(NAT) Natal	07:09 a.m.	2	DB		108
15	JJ 3686	TAM Linhas Aereas	(GIG) Rio De Janeiro	07:07 a.m.	2	DA		89
16	JJ 8026	TAM Linhas Aereas	(SCL) Santiago	7:35 AM	3		IA	265
17	JJ 3896	TAM Linhas Aereas	(SSA) Salvador	07:23 a.m.	2	DA		108
18	JJ 8125	TAM Linhas Aereas	(ASU) Asuncion	07:40 a.m.	3		IA	111
19	JJ 3614	TAM Linhas Aereas	(CGR) Campo Grande	08:06 a.m.	2	DB		89
20	JJ 3299	TAM Linhas Aereas	(POA) Porto Alegre	07:50 a.m.	2	DA		89
21	JJ 3466	TAM Linhas Aereas	(GYN) Goiania	07:55 a.m.	2	DB		89
22	JJ 8000	TAM Linhas Aereas	(EZE) Buenos Aires	07:55 a.m.	3		IA	184
23	JJ 3684	TAM Linhas Aereas	(GIG) Rio De Janeiro	08:05 a.m.	2	DA		89
24	JJ 8014	TAM Linhas Aereas	(AEP) Buenos Aires	08:12 a.m.	3		IA	111
25	JJ 3415	TAM Linhas Aereas	(FLN) Florianopolis	8:05 AM	2	DA		89
26	JJ 3490	TAM Linhas Aereas	(LDB) Londrina	08:10 a.m.	2	DB		89
27	JJ 3344	TAM Linhas Aereas	(CNF) Belo Horizonte	08:20 a.m.	2	DA		108
28	JJ 3362	TAM Linhas Aereas	(VIX) Vitoria	08:25 a.m.	2	DB		89
29	JJ 3562	TAM Linhas Aereas	(BSB) Brasilia	08:39 a.m.	2	DA		108
30	JJ 8046	TAM Linhas Aereas	(MVD) Montevideo	08:39 a.m.	3		IA	111
31	JJ 8130	TAM Linhas Aereas	(ROS) Rosario	09:02 a.m.	3		IA	111
32	JJ 3504	TAM Linhas Aereas	(REC) Recife	08:42 a.m.	2	DA		108
33	JJ 8066	TAM Linhas Aereas	(LIM) Lima	08:55 a.m.	3		IA	147
34	LA 757	LAN Airlines	(SCL) Santiago	9:15 AM	3		IA	96
35	JJ 3289	TAM Linhas Aereas	(POA) Porto Alegre	09:12 a.m.	2	DA		108
36	JJ 3748	TAM Linhas Aereas	(MAO) Manaus	09:30 a.m.	2	DB		119
37	JJ 3302	TAM Linhas Aereas	(FOR) Fortaleza	09:43 a.m.	2	DB		108
38	JJ 8094	TAM Linhas Aereas	(MIA) Miami	10:31 a.m.	3		IA	265
39	JJ 8086	TAM Linhas Aereas	(MCO) Orlando	10:45 AM	3		IA	147
40	JJ 3804	TAM Linhas Aereas	(SSA) Salvador	10:35 a.m.	2	DA		89
41	JJ 3554	TAM Linhas Aereas	(BEL) Belem	10:48 AM	2	DB		89
42	JJ 3320	TAM Linhas Aereas	(SLZ) Sao Luiz	10:50 a.m.	2	DB		89
43	AA 234	American Airlines	(MIA) Miami	11:40 a.m.	3		IA	222
44	JJ 3664	TAM Linhas Aereas	(AJU) Aracaju	11:03 a.m.	2	DB		89
45	JJ 3310	TAM Linhas Aereas	(NAT) Natal	11:16 a.m.	2	DB		108
46	JJ 3356	TAM Linhas Aereas	(JPA) Joao Pessoa	11:34 a.m.	2	DB		89
47	LA 4541	LAN Airlines	(EZE) Buenos Aires	12:15 p.m.	3		IA	111
48	JJ 8010	TAM Linhas Aereas	(AEP) Buenos Aires	12:15 p.m.	3		IA	111
49	JJ 3494	TAM Linhas Aereas	(GIG) Rio De Janeiro	12:19 p.m.	2	DA		77
50	JJ 3154	TAM Linhas Aereas	(SSA) Salvador	12:25 p.m.	2	DA		108
51	JJ 3329	TAM Linhas Aereas	(CWB) Curitiba	12:33 p.m.	2	DA		89
52	JJ 9772	TAM Linhas Aereas	(SCL) Santiago	12:44 p.m.	3		IA	111
53	JJ 3582	TAM Linhas Aereas	(BSB) Brasilia	12:50 p.m.	2	DA		89

	Code	Airline	Destination	Departure time	Check-in period	Domestic	International	Passengers
54	JJ 3636	TAM Linhas Aereas	(MCZ) Maceio	01:00 p.m.	2	DB		108
55	JJ 3878	TAM Linhas Aereas	(FOR) Fortaleza	12:57 p.m.	2	DB		108
56	JJ 3559	TAM Linhas Aereas	(IGU) Iguassu Falls	01:20 p.m.	2	DB		89
57	JJ 3355	TAM Linhas Aereas	(POA) Porto Alegre	01:27 p.m.	2	DA		89
58	JJ 3360	TAM Linhas Aereas	(CNF) Belo Horizonte	01:32 p.m.	2	DA		89
59	JJ 3692	TAM Linhas Aereas	(REC) Recife	01:40 p.m.	2	DA		89
60	JJ 3530	TAM Linhas Aereas	(GIG) Rio De Janeiro	01:50 p.m.	2	DA		89
61	PZ 707	TAM	(AGT) Ciudad del Este	02:05 p.m.	3		IA	111
62	JJ 3579	TAM Linhas Aereas	(BSB) Brasilia	02:20 p.m.	2	DA		89
63	JJ 3293	TAM Linhas Aereas	(POA) Porto Alegre	02:23 p.m.	2	DA		89
64	JJ 3331	TAM Linhas Aereas	(CWB) Curitiba	3:22 PM	2	DA		89
65	JJ 3894	TAM Linhas Aereas	(SSA) Salvador	03:28 p.m.	2	DA		108
66	JJ 3376	TAM Linhas Aereas	(VIX) Vitoria	03:30 p.m.	2	DB		89
67	LA 3506	LAN Airlines	(BOG) Bogota	3:50 PM	3		IA	147
68	JJ 3612	TAM Linhas Aereas	(BPS) Porto Seguro	3:55 PM	2	DB		89
69	JJ 3185	TAM Linhas Aereas	(FLN) Florianopolis	03:40 p.m.	2	DA		89
70	LA 751	LAN Airlines	(SCL) Santiago	03:56 p.m.	3		IA	184
71	JJ 3548	TAM Linhas Aereas	(REC) Recife	04:05 p.m.	2	DA		108
72	JJ 3492	TAM Linhas Aereas	(RAO) Ribeirao Preto	04:05 p.m.	2	DB		77
73	JJ 3592	TAM Linhas Aereas	(CGR) Campo Grande	04:25 p.m.	2	DB		89
74	JJ 3546	TAM Linhas Aereas	(GYN) Goiania	04:30 p.m.	2	DB		89
75	JJ 3507	TAM Linhas Aereas	(POA) Porto Alegre	04:38 p.m.	2	DA		108
76	JJ 3876	TAM Linhas Aereas	(CGB) Cuiaba	04:50 p.m.	2	DB		89
77	IB 6824	Iberia	(MAD) Madrid	04:57 p.m.	3		IB	258
78	JJ 3337	TAM Linhas Aereas	(CWB) Curitiba	05:05 p.m.	2	DA		89
79	JJ 3396	TAM Linhas Aereas	(LDB) Londrina	05:15 p.m.	2	DB		89
80	LA 753	LAN Airlines	(SCL) Santiago	5:30 PM	3		IA	184
81	JJ 3516	TAM Linhas Aereas	(REC) Recife	05:31 p.m.	2	DA		89
82	JJ 3326	TAM Linhas Aereas	(CNF) Belo Horizonte	05:30 p.m.	2	DA		89
83	PZ 722	TAM	(EZE) Buenos Aires	05:28 p.m.	3		IA	111
84	JJ 3113	TAM Linhas Aereas	(FLN) Florianopolis	05:40 p.m.	2	DA		89
85	JJ 3510	TAM Linhas Aereas	(GIG) Rio De Janeiro	05:45 p.m.	2	DA		89
86	BA 246	British Airways	(LHR) London	06:01 p.m.	3		IB	221
87	LA 761	LAN Airlines	(SCL) Santiago	7:00 PM	3		IA	111
88	QR 771	Qatar Airways	(EZE) Buenos Aires	06:50 p.m.	3		IA	184
89	JJ 3386	TAM Linhas Aereas	(BEL) Belem	06:55 p.m.	2	DB		89
90	JJ 8008	TAM Linhas Aereas	(AEP) Buenos Aires	07:39 p.m.	3		IA	111
91	JJ 3668	TAM Linhas Aereas	(GIG) Rio De Janeiro	07:33 p.m.	2	DA		77
92	JJ 3555	TAM Linhas Aereas	(CWB) Curitiba	8:10 PM	2	DA		89
93	JJ 3849	TAM Linhas Aereas	(POA) Porto Alegre	07:45 p.m.	2	DA		89
94	JJ 3498	TAM Linhas Aereas	(REC) Recife	07:44 p.m.	2	DA		108
95	JJ 3178	TAM Linhas Aereas	(SSA) Salvador	08:00 p.m.	2	DA		108
96	JJ 3750	TAM Linhas Aereas	(MAO) Manaus	08:05 p.m.	2	DB		108
97	LA 2766	LAN Airlines	(LIM) Lima	08:25 p.m.	3		IA	147
98	JJ 8028	TAM Linhas Aereas	(SCL) Santiago	8:50 PM	3		IA	111
99	JJ 3630	TAM Linhas Aereas	(CGB) Cuiaba	09:35 p.m.	2	DB		89
100	JJ 8106	TAM Linhas Aereas	(COR) Cordoba	09:40 p.m.	3		IA	111
101	JJ 8030	TAM Linhas Aereas	(MVD) Montevideo	09:45 p.m.	3		IA	111
102	JJ 3398	TAM Linhas Aereas	(SSA) Salvador	09:50 p.m.	2	DA		89
103	JJ 3316	TAM Linhas Aereas	(NAT) Natal	10:05 p.m.	2	DB		89
104	JJ 8070	TAM Linhas Aereas	(FRA) Frankfurt	10:10 p.m.	3		IB	265
105	JJ 3180	TAM Linhas Aereas	(BSB) Brasilia	10:15 p.m.	2	DA		89
106	JJ 8062	TAM Linhas Aereas	(MXP) Milan	10:20 p.m.	3		IB	184
107	JJ 3335	TAM Linhas Aereas	(CWB) Curitiba	10:25 p.m.	2	DA		89
108	JJ 3295	TAM Linhas Aereas	(POA) Porto Alegre	10:25 p.m.	2	DA		108
109	JJ 8017	TAM Linhas Aereas	(ASU) Asuncion	10:25 p.m.	3		IA	111
110	JJ 3442	TAM Linhas Aereas	(CNF) Belo Horizonte	10:35 p.m.	2	DA		89
111	JJ 8108	TAM Linhas Aereas	(CDG) Paris	10:35 p.m.	3		IB	265
112	JJ 3443	TAM Linhas Aereas	(GIG) Rio De Janeiro	10:35 p.m.	2	DA		89

	Code	Airline	Destination	Departure time	Check-in period	Domestic	International	Passengers
113	*AA 906*	*American Airlines*	*(MIA) Miami*	*10:40 PM*	*3*		*IA*	*222*
114	*JJ 8064*	*TAM Linhas Aereas*	*(MAD) Madrid*	*10:40 p.m.*	*3*		*IB*	*147*
115	*JJ 8080*	*TAM Linhas Aereas*	*(JFK) New York*	*11:05 PM*	*3*		*IA*	*184*
116	*AA 950*	*American Airlines*	*(JFK) New York*	*11:10 PM*	*3*		*IA*	*222*
117	*JJ 3666*	*TAM Linhas Aereas*	*(THE) Teresina*	*11:15 p.m.*	*2*	*DB*		*89*
118	*JJ 3358*	*TAM Linhas Aereas*	*(JPA) Joao Pessoa*	*11:20 p.m.*	*2*	*DB*		*89*
119	*JJ 3159*	*TAM Linhas Aereas*	*(FLN) Florianopolis*	*11:20 p.m.*	*2*	*DA*		*89*
120	*JJ 3644*	*TAM Linhas Aereas*	*(MCZ) Maceio*	*11:25 p.m.*	*2*	*DB*		*108*
121	*JJ 8090*	*TAM Linhas Aereas*	*(MIA) Miami*	*11:40 PM*	*3*		*IA*	*265*
122	*JJ 8112*	*TAM Linhas Aereas*	*(MEX) Mexico City*	*11:40 PM*	*3*		*IA*	*184*
123	*AA 962*	*American Airlines*	*(DFW) Dallas*	*11:40 PM*	*3*		*IA*	*222*
124	*JJ 8084*	*TAM Linhas Aereas*	*(LHR) London*	*11:45 p.m.*	*3*		*IB*	*265*
125	*JJ 3506*	*TAM Linhas Aereas*	*(REC) Recife*	*11:55 p.m.*	*2*	*DA*		*108*
126	*JJ 8102*	*TAM Linhas Aereas*	*(JFK) New York*	*12:05 AM*	*3*		*IA*	*147*
127	*JJ 3557*	*TAM Linhas Aereas*	*(IGU) Iguassu Falls*	*12:05 a.m.*	*2*	*DB*		*77*
128	*JJ 3322*	*TAM Linhas Aereas*	*(FOR) Fortaleza*	*12:26 a.m.*	*2*	*DB*		*108*
129	*AA 216*	*American Airlines*	*(LAX) Los Angeles*	*12:10 a.m.*	*3*		*IA*	*192*
130	*IB 6820*	*Iberia*	*(MAD) Madrid*	*12:31 a.m.*	*3*		*IB*	*258*
131	*AA 930*	*American Airlines*	*(MIA) Miami*	*02:01 a.m.*	*3*		*IA*	*222*
132	*JJ 3646*	*TAM Linhas Aereas*	*(REC) Recife*	*03:06 a.m.*	*2*	*DA*		*108*

Annex 3: Other case study results

Table 56 - Queue results - CACCAP model (without constraints 4.6 and 4.7) – FDS 1

Time interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Length (min)	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Pass	0	0	22	78	126	48	18	0	0	0	20	199	383	321	413	202	147	132	141	215	147	156	242	284
λ	0.00	0.00	0.73	2.60	4.20	1.60	0.60	0.00	0.00	0.00	0.67	6.63	12.77	10.70	13.77	6.73	4.90	4.40	4.70	7.17	4.90	5.20	8.07	9.47
U	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Desks (S)	1	1	2	5	9	3	2	1	1	1	2	13	25	22	27	14	10	8	10	14	10	10	17	18
Change arrival rate				3.55	1.62	0.38	0.38					9.95	1.92	0.84	1.29	**0.49**	0.73	0.90	1.07	1.52	0.68	1.06	1.55	1.17
Change # of servers				2.50	1.80	0.33	0.67					6.50	1.92	0.88	1.23	**0.52**	0.71	0.80	1.25	1.40	0.71	1.00	1.70	1.06
$\rho = \lambda / (S*U)$			0.73	**1.04**	0.93	**1.07**	0.60				0.67	**1.02**	**1.02**	0.97	**1.02**	0.96	0.98	**1.10**	0.94	**1.02**	0.98	**1.04**	0.95	**1.05**

Time interval	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Length (min)	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Pass	264	195	107	146	303	384	355	337	291	205	55	100	166	255	227	271	421	465	454	337	277	210	175	25
λ	8.80	6.50	3.57	4.87	10.10	12.80	11.83	11.23	9.70	6.83	1.83	3.33	5.53	8.50	7.57	9.03	14.03	15.50	15.13	11.23	9.23	7.00	5.83	0.83
U	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Desks (S)	18	13	7	10	20	25	24	23	19	14	3	7	12	14	15	20	27	32	31	23	18	14	12	2
Change arrival rate	0.93	0.74	0.55	1.36	2.08	1.27	0.92	0.95	0.86	**0.70**	**0.27**	1.82	1.66	1.54	0.89	1.19	1.55	1.10	0.98	**0.74**	0.82	0.76	**0.83**	0.14
Change # of servers	1.00	0.72	0.54	1.43	2.00	1.25	0.96	0.96	0.83	**0.74**	**0.21**	2.33	1.71	1.17	1.07	1.33	1.35	1.19	0.97	**0.74**	0.78	0.78	**0.86**	0.17
$\rho = \lambda / (S*U)$	0.98	**1.00**	**1.02**	0.97	**1.01**	**1.02**	0.99	0.98	**1.02**	0.98	**1.22**	0.95	0.92	**1.21**	**1.01**	0.90	**1.04**	0.97	0.98	0.98	**1.03**	**1.00**	0.97	0.83

Table 57 - Queue results - CACCAP model (without constraints 4.6 and 4.7) – FDS 2

Time interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Length (min)	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Pass	75	58	22	0	11	33	60	67	40	67	123	252	267	235	150	98	117	174	164	174	153	99	47	36
λ	2.50	1.93	0.73	0.00	0.37	1.10	2.00	2.23	1.33	2.23	4.10	8.40	8.90	7.83	5.00	3.27	3.90	5.80	5.47	5.80	5.10	3.30	1.57	1.20
U	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Desks (S)	5	4	2		1	2	4	5	3	5	8	17	18	15	10	7	7	12	11	12	10	7	3	3
Change arrival rate		0.77	0.38			3.00	1.82	1.12	0.60	1.68	1.84	2.05	1.06	**0.88**	**0.64**	0.65	1.19	1.49	0.94	1.06	0.88	0.65	0.47	0.77
Change # of servers		0.80	0.50			2.00	2.00	1.25	0.60	1.67	1.60	2.13	1.06	**0.83**	**0.67**	0.70	1.00	1.71	0.92	1.09	0.83	0.70	0.43	1.00
$\rho = \lambda / (S*U)$	**1.00**	0.97	0.73		0.73	**1.10**	**1.00**	0.89	0.89	0.89	**1.03**	0.99	0.99	**1.04**	**1.00**	0.93	**1.11**	0.97	0.99	0.97	**1.02**	0.94	**1.04**	0.80

Time interval	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Length (min)	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Pass	47	55	93	121	81	67	103	126	134	123	124	118	110	96	133	164	253	320	394	294	225	115	57	44
λ	1.57	1.83	3.10	4.03	2.70	2.23	3.43	4.20	4.47	4.10	4.13	3.93	3.67	3.20	4.43	5.47	8.43	10.67	13.13	9.80	7.50	3.83	1.90	1.47
U	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Desks (S)	3	4	7	8	5	5	6	9	9	8	8	9	6	7	8	10	15	25	27	19	15	8	4	3
Change arrival rate	1.31	1.17	1.69	1.30	0.67	0.83	1.54	1.22	1.06	0.92	1.01	0.95	0.93	0.87	1.39	1.23	1.54	1.26	1.23	**0.75**	0.77	**0.51**	0.50	0.77
Change # of servers	1.00	1.33	1.75	1.14	0.63	1.00	1.20	1.50	1.00	0.89	1.00	1.13	0.67	1.17	1.14	1.25	1.50	1.67	1.08	**0.70**	0.79	**0.53**	0.50	0.75
$\rho = \lambda / (S*U)$	**1.04**	0.92	0.89	**1.01**	**1.08**	0.89	**1.14**	0.93	0.99	**1.03**	**1.03**	0.87	**1.22**	0.91	**1.11**	**1.09**	**1.12**	0.85	0.97	**1.03**	**1.00**	0.96	0.95	0.98

Table 58 - DACCAP results – FDS 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Flight	8	9	12	13	14	15	17	19	20	21	23	25	26	27	28	29	32	35	36	37	40	41
Check-in period	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Departure	7	9	15	15	15	15	15	17	16	16	17	17	17	17	17	18	18	19	20	20	22	22
	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number of	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	3	3
required desks	5	5	5	4	5	4	5	4	4	4	4	4	4	5	4	5	5	4	4	4	3	3
by time interval		4																				
		2																				
Largest desk	1	7	35	30	15	24	1	40	20	6	28	34	10	14	29	24	19	1	28	8	14	12
number	3	8	37	32	17	26	3	40	22	8	28	35	12	16	31	24	21	4	28	11	16	13
assigned to	5	10	39	33	19	27	5	40	23	9	28	36	13	18	32	26	21	4	28	11	16	13
flight f by time		9																				
interval		7																				

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Flight	42	44	45	46	49	50	51	53	54	55	56	57	58	59	60	62	63	64	65	66	68	69
Check-in period	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Departure	22	23	23	24	25	25	26	26	27	26	27	27	28	28	28	29	29	31	31	32	32	32
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Number of	3	3	4	3	3	4	3	3	4	4	3	3	3	3	3	3	3	3	4	3	3	3
required desks	3	3	4	3	3	4	3	3	4	4	3	3	3	3	3	3	3	3	4	3	3	3
by time interval																						
Largest desk	5	8	1	38	5	7	37	30	33	14	20	17	40	4	1	12	13	32	38	7	4	34
number	7	10	4	40	6	10	39	32	36	16	22	19	40	6	3	12	15	32	39	9	6	35
assigned to	7	10	4	40	6	10	39	32	36	16	22	19	40	6	3	12	15	32	39	9	6	35
flight f by time																						
interval																						

	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
Flight	71	72	73	74	75	76	77	78	79	81	82	84	85	86	89	91	92	93	94	95	96	99
Check-in period	2	2	2	2	2	2	3	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2
Departure	33	33	33	34	34	34	34	35	35	36	36	36	36	37	38	40	41	40	40	41	41	44
	1	1	1	1	1	1	2	1	1	1	1	1	1	4	2	2	2	2	2	2	2	2
Number of	4	3	3	3	4	3	5	3	3	3	3	3	3	5	3	2	3	3	3	3	3	3
required desks	4	3	3	3	4	3	7	3	3	3	3	3	3	4	3	2	3	3	3	3	3	3
by time interval							4							2								
							1							1								
Largest desk	40	20	23	26	17	30	12	4	7	28	32	27	1	36	24	38	7	22	35	2	32	39
number	40	20	23	26	17	31	14	6	9	30	33	27	3	37	25	38	8	23	36	3	33	40
assigned to	40	20	23	26	17	31	16	6	9	30	33	27	3	37	25	38	8	23	36	3	33	40
flight f by time							13							37								
interval							10							37								

	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Flight	102	103	104	105	106	107	108	110	111	112	114	117	118	119	120	124	125	127	128	130
Check-in period	2	2	3	2	3	2	2	2	3	2	3	2	2	2	2	3	2	2	2	3
Departure	44	45	45	45	45	45	45	46	46	46	46	47	47	47	47	48	48	1	1	2
	2	2	5	2	3	2	2	2	5	2	3	2	2	2	2	5	2	1	1	2
Number of	3	3	6	3	5	3	3	3	6	3	4	3	3	3	3	6	3	2	3	4
required desks	3	3	5	3	3	3	3	3	5	3	3	3	3	3	3	5	3	3	5	6
by time interval			3		2				3		2					3				5
			1		1				1		1					1				2
Largest desk	36	21	25	14	30	2	5	16	10	27	18	37	8	39	24	34	20	9	11	2
number	37	22	26	14	32	3	6	17	11	28	19	37	8	40	24	35	20	9	13	4
assigned to	37	22	26	14	30	3	6	17	11	28	19	37	8	40	24	34	20	9	15	6
flight f by time			25		29				11		19					32				5
interval			25		29				11		18					30				5

Table 59 - DACCAP results – FDS 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Flight	7	10	11	16	18	22	24	30	31	33	34	38	39	43	47	48	52	61	67
Check-in period	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Departure	5	11	12	16	16	16	17	18	18	18	19	22	22	24	25	25	26	29	32
Number of required desks by time interval	2	1	1	2	1	2	1	1	1	1	1	3	2	2	1	1	1	1	2
	3	2	2	4	2	3	2	2	2	2	2	5	3	4	2	2	2	2	3
	5	3	3	6	3	5	3	3	3	4	3	7	4	6	3	3	3	3	4
	4	2	2	5	2	4	2	2	2	3	2	4	2	3	2	2	2	2	2
	2	1	1	2	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1
Largest desk number assigned to flight f by time interval	2	29	26	25	15	20	11	14	2	8	6	15	6	25	3	6	2	27	4
	3	29	26	27	16	21	12	15	2	9	7	17	7	27	4	7	2	28	5
	5	29	26	29	17	23	13	16	3	11	8	19	8	29	5	8	3	29	6
	4	29	26	29	17	23	13	16	3	11	8	19	8	29	5	8	3	29	6
	2	29	26	29	17	23	13	16	3	11	8	19	8	29	5	8	3	29	6

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Flight	70	80	83	87	88	90	97	98	100	101	109	113	115	116	121	122	123	126	129	131
Check-in period	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Departure	32	36	35	39	38	40	41	42	44	44	45	46	47	47	48	48	48	1	1	5
Number of required desks by time interval	2	2	1	2	3	2	3	2	2	2	2	4	3	4	5	3	4	1	2	2
	4	4	2	3	5	3	4	3	3	3	3	5	5	5	6	5	5	2	3	3
	5	5	3	2	3	2	3	2	2	2	2	4	3	4	5	3	4	4	5	5
	3	3	2	1	2	1	2	1	1	1	1	2	2	2	3	2	2	3	4	4
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Largest desk number assigned to flight f by time interval	26	19	28	28	4	26	24	4	13	16	11	24	20	4	10	16	29	11	21	2
	28	21	29	29	6	27	25	5	14	17	12	25	21	5	10	16	29	12	22	3
	29	22	29	29	6	27	25	5	14	17	12	25	19	4	10	16	29	14	22	5
	27	22	29	29	6	27	25	5	14	17	12	24	18	4	10	16	29	14	22	5
	25	22	29	29	6	27	25	5	13	16	11	24	17	4	10	16	29	14	22	5