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BUS FLEET SIZE DIMENSIONING IN AN INTERNATIONAL AIRPORT USING DISCRETE EVENT SIMULATION

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ABSTRACT

The continuous growth of airport operations generates continuous infrastructure expansion needs at international airports. In some cases, in the face of limitations in short-term expansions, the immediate solution is the creation of remote positions that allow a greater number of flights to be attended but which require the use of bus fleets to attend passenger boarding and disembarking operations. The sizing of the buses will allow to reduce the waiting times of flights below the level of service required by international standards. For this purpose, the development of a discrete event simulation model integrated to the transactional flight database is proposed. In the literature, although many references to simulation models have been found in airports, they have not been specifically focused in order to size and manage the bus fleet. Simulation experiments of this model under the management of scenarios allows to identify the bus fleet size required.

1 INTRODUCTION

The growth of airport operations globally generates constant modification and infrastructure requirements in international airports to maintain service standards. Due to space constraints, the construction of new terminals is not always viable. A common way of meeting transportation needs is to increase the boarding and disembarking positions of flights to serve a growing number of flights. The airplanes are parked in these positions and passengers board the airplanes preferably by passenger loading bridges (PLB) directly from the departure rooms. If the PLB are occupied, they use buses to move from the departure lounges to the positions. In this second case, these positions are called “remote positions”. Since they do not require PLB, they can generally be located in areas peripheral to the terminal of the airport. It is clear that the attention of the passengers by the PLB implies a process of boarding much quicker and more comfortable for the passenger. But these sleeves are limited to the available infrastructure of the terminal because they must be located from it to the positions near the airport. As the infrastructure limitation is a temporary problem in the international airport under study, the growth of operations has been reflected in an increase in remote positions. This is a contingency measure against expansion projects of a new terminal estimated for 10 years on average. this paper presents a critical issue related to bus fleet management and sizing for the transport of passengers from/to the remote positions.

In order to present this work, section 2 presents literature related to infrastructure issues in international airports management . Section 3 presents the problems statement. Section 4 establishes the model proposal for this problem while section 5 presents the detailed case study approached. Finally, in section 6 the results will be presented and analyzed.

2 LITERATURE REVIEW

Several authors have studied different airport processes using discrete event simulation. Most of past researchers have focused on modelling processes related on the airport arrival and departure passengers processes (Guizzi et al. 2014; Appelt et al. 2007; Rauch R., and Kljajic M. 2006)). They usually focus on check in counter sizing, security controls, migration processes and others. Simulation objectives in this previous researches are related to determine optimum resource sizing for the different processes mentioned. The results obtained were effective to determine the number of resources need to satisfy service standards and mainly reduce in process waiting queues.

There are fewer researches related to peripheral processes such as aircraft preparation or resources and general airport management. Gate allocation to current incoming and outgoing flights is one of these key points processes. Some of these previous works have been developed using discrete event simulation models but also other simulation methods as Monte Carlo Simulation for more specific issues. For instance (Smits, Hartjes and Mitici 2018) related this method for noise analysis in aircraft departure processes to determine the estimate impacts of departures in awakenings of surrounding areas of an airport.

Certain simulation models have been developed to model different problems, usually as side tools in aid of optimization (Lee 2014; Mujica 2015; Mujica and Flores 2017). Other methods as algorithmic frameworks based on "sim-opt" to deal with capacity problems are recent approaches for this problems (Scala, Mujica,Wu and Delaheye 2018).

Currently most of past simulation works related to gate processes focus on gate assignment or allocation to flights during peak times. In most cases, big international airport do have a bigger service infrastructure with a minimum number of gates without PLB as in the case of study. Therefore, a more close related situation can be check in the Latin American region where some international airports do have a more intensive level of support bus fleets to transport passengers. However, they focus mainly in arriving flights. At international level, internal transportation problems relate directly to the situation in our case. For instance (Jung et al 2017) has dealt with intermodal transportation in terminals which switch between ground and air transportation in a similar way for passengers movements using simulation and scenario evaluation to evaluate the situation.

Even as similar as this approach is it still has big differences related to the situation described in the airport case study. The analyzed process isn't an external terminal transportation process but an internal transportation process in the final stage of aircraft boarding and disembarking. The closest past investigations on this subject can be found in simulation models of ground operations, for instance (El Asri et al 2018) focused on an extense literature review on this subject that deals within many problems with vehicle allocation. More specific applications developed in recent dates include (Weiszer et al. 2015) that focus on minimizing costs of ground operations by adequate routing and scheduling, or (Fitouri-Trabelsi et al 2014) that focus on information management of ground operations and (Kwasiborska 2010) that focus on increasing ground operations capacity relating them to passenger flow from flights to increase response levels. Even tho this past research do relate to ground operations they don't actually focus on specifically fleet sizing as the current research does.

3 PROBLEM STATEMENT AND PROPOSAL

Within the framework of national and international departure and arrival flight attendant operations at the airport under study, a main critical problem is to ensure the service standard by avoiding delays in each of the processes involved in both passenger boarding and disembarking. . One of the critical services has to do during peak service periods of the airport with the limited availability of passenger loading bridges (PLB) so that passengers can get on or off planes. In the international airport of the case study that will be presented and discussed later there are about 40 boarding gates at the airport, but only about 25 of them have PLBs for passenger attention. This means that a significant part of the operations (around 36%) require the use of buses to take passengers from boarding gates to remote locations where they board aircrafts in boarding processes ; or when a plane arrives to transport passengers disembarking from remote positions to the baggage pick-up areas or inbound migration registration. Given that the use of these buses requires internal traffic through the airport, through signposted roads, and remote locations are located in peripheral areas, the transfer of these passengers at peak times considering the existing demand has been converted in recent years into a critical problem. This service has become a bottleneck that began to generate significant delays (of around 10 minutes or more according to the scheduled start of boarding time), especially during peak times.

It is at this juncture that the problem of managing buses that serve remote locations becomes a critical issue. The number of buses available has a direct impact on the time of boarding or disembarking of flights in the remote positions. There are international standards that must be met regarding these times without mentioning that the level of satisfaction of the passenger is directly involved in this time. An insufficient sizing of buses generates longer waiting queues in boarding rooms, more extensive boarding process and high waiting times when passengers have already landed and hope to be able to get off the plane to address the arrival migrations processes in case of international flights and baggage pick-up on flights of national arrival. Due to this problem is that it is proposed as an immediate solution possibility to expand the initial fleet of buses available from 10 units to an adequate number of buses that can meet the attention of the flights in the peak period by satisfying the target service level of the administration of the airport.

The need to propose a model capable of efficiently dimensioning the size of the fleet of these buses was identified so as to comply with the standards of passenger attention time. The solution to be generated must consider the nature of the management and attention system of the bus fleet that has defined transport systems, interruptions due to aircraft movements, restrictions on transport capacity with respect to variable flight capacities, restrictive speeds by tranches, change of policies in the allocation of buses to flights among others but not mentioned. Employing a discrete simulation model is a viable option because of the ability to model all the conditions previously described. The construction of a model can also reflect the stochastic conditions within the scope of said process. It is considered that the model is a useful base to study configurations, change parameters and test management conditions. That allows to identify not only the size of the required bus fleet but also the management policies of the bus fleet. Better results are reflected in the process indicators referring to passenger embarkation and disembarkation processes.

4 THE SIMULATION MODEL OF FLEET BUS MANAGEMENT

The simulation model contemplates the creation of national / international departure / arrival flights and assigns them according to priority availability to gates with PLBs. If the gates are occupied, the model proceeds to assign gates without PLBs that make use of the shuttle service with buses. In the case of departure flights, the start of the process is contemplated when the flight is assigned to a gate and the end of the process when the flight ends using the gate with a PLB or the remote position depending on the case that corresponds. In the case of incoming flights, the assignment of the flight to a remote gate or gate is considered as the start of the process and the end thereof when, on the one hand, the passengers arrive at the national or international terminal and the remote position has been vacated. , or the end of the use of the gate with PLB as it corresponds to the case. Rockwell´s Arena was used to build the simulation model, the general model is divided by functional sub models, the general structure of the sub models relation is summarized in the logic described in Figure 1.

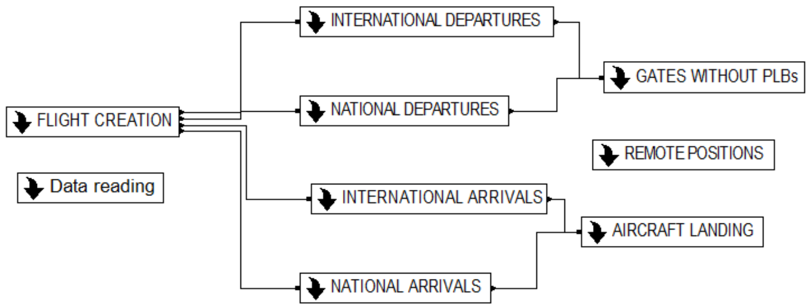

Figure 1: Sub model structure for the simulation model.

In the following pages, each of the sub modes presented will be described in order to explain the detailed logic considered in the creation of each one.

4.1 Data Reading

In this module of the model, the flight information contained in an external file is extracted. The information is transferred to variables and attributes of the model that will then be accessible for the definition of the flights and the operational restrictions discussed in the previous section.

To record each flight, it is necessary to define the scheduled day, hour and minute of the flight. In case of an arrival flight, it will be the day, hour and minute in which the flight arrives at the international airport. In case of an outbound flight, it will be the scheduled departure time according to the flight's itinerary. It must also be indicated if it is a departure or arrival flight, if it is of national or international origin, the airline to which it belongs, the size classification of the aircraft associated with the flight and finally the expected number of passengers on the flight.

4.2 Flight Creation

At the end of the module, flights are divided according to the four possible categories: international departures, national departures, international arrivals and national arrivals. The general logic of the process can be seen in Figure 2.

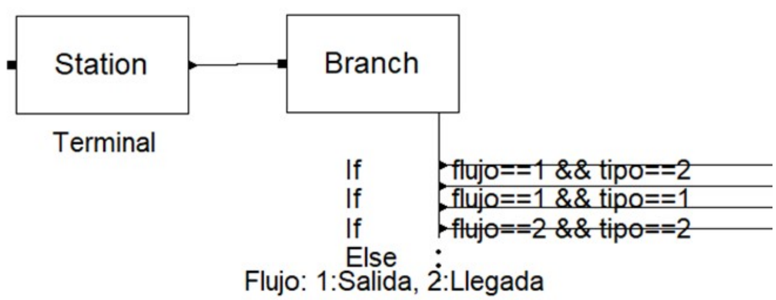

Figure 2: Flight creation sub model detailed view.

4.3 Departures

This module simulates the logic of assignment of flights to gates with PLB and gates without PLB. In the case of gates with PLB the scope of the simulation culminates after occupying the PLB for the on board passengers plus a offset of time that corresponds to the flight preparation before takeoff. In the case of gates without PLB, a gate is assigned for the boarding process and the entity related to the flight continues to the Gates without PLB sub model.

4.4 Arrivals

In the Arrivals sub model, a gate with PLB is assigned to flights arriving at the IA. In the case of flights with gate with assigned beam, the range ends after a time of occupation of the beam. In the case of flights without gate with PLB, the entity proceeds to the Remote positions sub model.

4.5 Gates without PLBs

In this sub model, each departure flight generates bus use requirements according to the number of passengers and flight crew. The current policy was to assign movements according to the number of passengers per flight plus an additional initial movement exclusively for crew members. This policy was later replaced in the scenario evaluation assigning a private shuttle for crews in order be able to use the buses just for passenger transportation needs. To be able to properly modify the model for both scenarios a extra variable was defined to assign on and off the extra bus movement for crew members.

4.6 Aircraft Landing

In this module, incoming flights that did not manage to access a gate with PLB are positioned in a remote position. In each of the remote locations, buses are requested for the transfer of passengers to the terminals of the national and international baggage pick-up area/inbound migration zones depending on the flight. Figure 3 shows the general logic of the sub model.

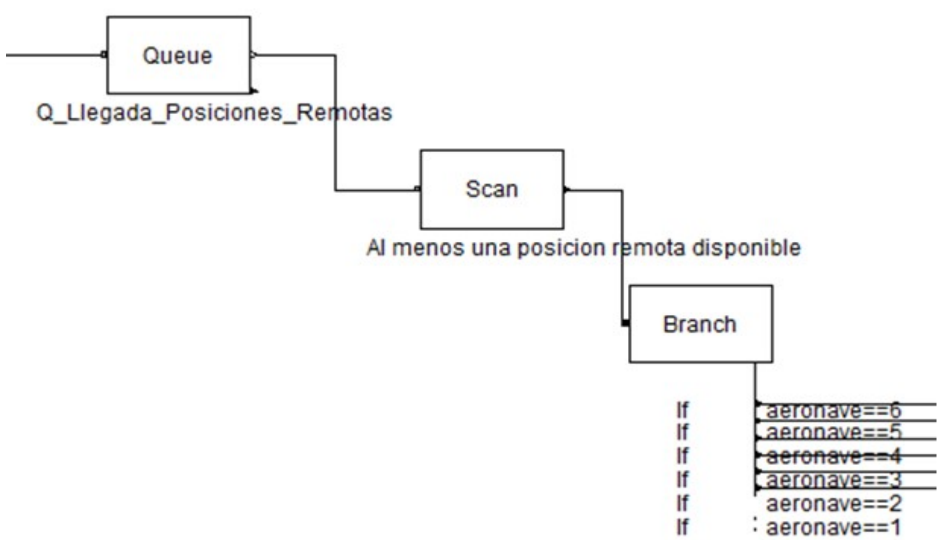

Figure 3: Aircraft landing sub model detailed view.

4.7 Remote Positions

In this module buses from gates without PLB arrive and unload passengers. Passengers board the planes and the end of the process reaches the beginning of the takeoff process when the remote position is released to be assigned for another departure or arrival flight in the preceding sub models. The general logic of this sub model is shown in Figure 4.

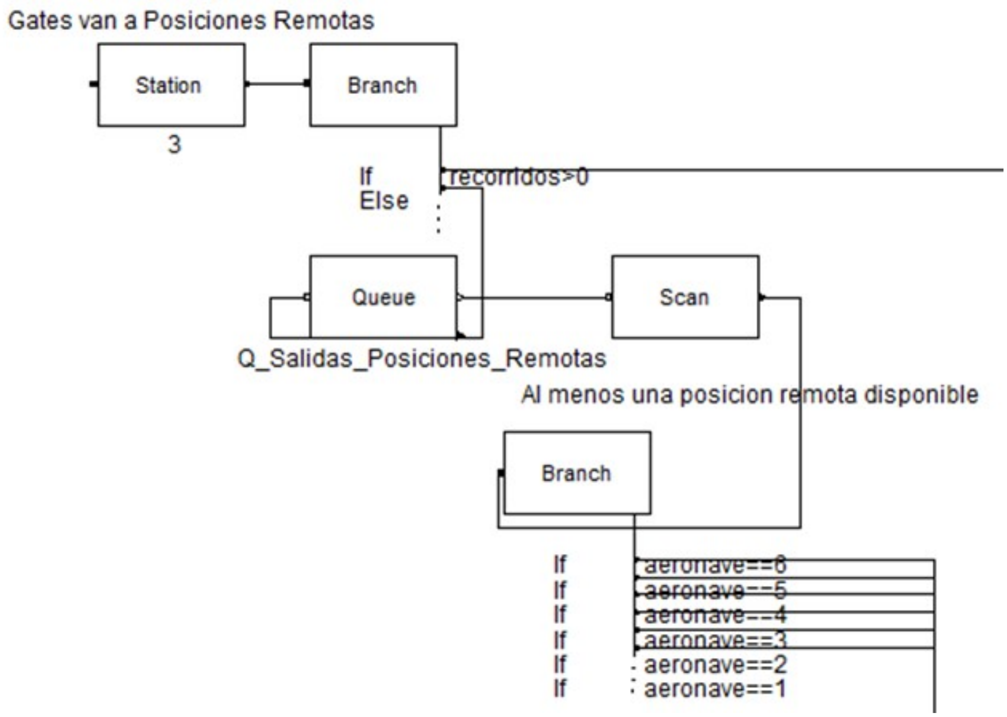

Figure 4: Remote position sub model detailed view.

5 CASE STUDY

An international airport in Lima, Perú is taken as a reference of a case study for this model. In this section, detailed information about of (1) the analysis of the information, (2) design of a simulation model of the bus service operation and (3) validation in relation to bus service for transfer of crew and passengers of domestic flights of departure and arrival to internationals in remote positions will be exposed.

5.1 Input Data Analysis

For the elaboration of the model, diverse sources of information are used. Among the main ones are the following:

- Itinerary of flights of the International Airport (IA)
- Average occupation level per airline.
- Capacity of the different models of ships that operate in the IA
- Database of the current bus management system.

The information is analyzed and classified to determine the input data of the model..

5.1.1 Flight information management

There are three data entry types necessary for the model. These are: "National Departure Flights", "International Departure Flights" and "Arrival Flights" variables. To make a simpler use of the information all variables used were numerically coded. Table 1 shows the flight related variables used by the model.

All the aforementioned data are obtained from the flight itinerary, with the exception of the number of passengers obtained based on the capacity of the aircraft multiplied by the load factor corresponding to the airline. For this purpose the load factor is treated as a stochastic variable based on historical data driven by hour interval and airway. The number of passengers per flight is fundamentally important since it allows the subsequent determination of the number of buses to be assigned to each flight in case it is assigned to a remote location.

5.1.2 Bus Travel Distances

The distance between each pair of possible points of displacement of the buses in the IA is defined. This information was calculated from the information provided in the layout of the airport. The distances have been calculated in meters and are copied to the simulation model so that it can be calculated according to the displacements of the buses and their speed of movement. It should be noted that this spreadsheet, unlike the previous one, is not one that is read directly by the model, but is manually copied in the definition of elements of the simulation model. Table 2 shows the detail of the structure of the distance table. The columns "Starting Station" and "Ending Station" refer to the positions as they are identified as stations within the simulation model, and for each pair the distance in meters is specified in the “Distances” column.

Table 2 does not only contains the distances between terminals and remote positions, but also all possible distances, even between remote positions and between terminals, because in peak hours it is possible that buses do not return to their base between each attention but move from one position to another after completing a transfer in order to attend pending movement requests from other flights. A total of 7,311 stretches are considered in this matrix, and depending of the flight requirement from a specific starting position to a specific ending position the stretches are combined to from a travel route for the bus operation and distances are sum according to it.

5.1.3 Remote Parking Positions

A matrix is defined in which all the remote positions are linked to each other according to the numbering in the layout. The matrix contains binary values according to the following rule:

0: Indicates that the remote positions corresponding to row and column cannot be used simultaneously.
1: Indicates that it is possible to use the remote positions corresponding to row and column simultaneously.

Table 1: Flight related variables coding.

CODE	VARIABLE	Values
C1	**DAY**	Integer between 0 and 23
C2	**HOUR**	Integer between 1 and 8
C3	**MINUTE**	Integer between 0 and 59
C4	**TYPE**	
	National	1
	International	2
C5	**FLOW**	
	Outbound	1
	Inbound	2
C6	**AIRWAYS**	
	AEROLINEAS ARGENTINAS	1
	AEROMEXICO	2
	AIR CANADA	3
	…	…
	JET BLUE	24
C7	**AIRCRAFT SIZES**	
	A	1
	B	2
	C	3
	D	4
	E	5
	F	6
C8	**PASSENGERS PER FLIGHT**	Integer

Table 2: Travel Distances by stretch.

Starting station	Ending station	Distances
1	EPA2	1083
1	TB	1084
1	7A	469
1	7B	435
1	7	491

A part of the matrix is shown in Table 3. It can be seen by way of example that the row of the remote position 27 has a 0 in the column of the remote position 33. This indicates that in case the remote position 27 is automatically occupied in the model it will disable the remote position 33. This is due to the configuration of positions in the layout, which means that in some cases positioning aircraft in certain positions disables the ability to use remote positions adjacent to that position.

Table 3: Travel Distances by stretch.

	1	2	3	4	5	6	7	7A	7B	27	28	29	33	33L	33R	34	34L	34R	35	35L	35R
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1
28	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1
29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

5.1.4 Gates management and coding

Within the process of attention of domestic / international flights both departure and arrival there are two possible mechanisms for transferring passengers from the gate to the plane. The first of these mechanisms are the passenger loading bridges (PLB) that allow passengers to directly approach the plane from the gate. The IA has 19 gates with PLBs (Gates 8 to 26). Although the priority is that they are always used because they allow a more comfortable and faster approach in case there are many flights in a time slot it is possible to assign them to gates 1 to 7 or 27 to 39 that correspond to gates without PLBs in the first floor of the airport that transports passengers to the plane using buses.

The type of flight (national or international) is the first criteria to determine if a gate can be assigned to a flight. This distribution can change during a regular day depending if its international o national peak times in the airport. Swing gates are used to modify the available waiting zones for national and international passengers. International departure flights have priority in the assignation of gates with PLBS. If there are many international flights in a time segment, the earliest to depart flight has the highest priority in gate with PLB assignment, meaning the flight queue is based on a Low Value First rule based on departure time.

The information of the detailed number of positions and the position capacity in terms of aircraft size is shown in Table 4.

Table 4. Travel Distances by stretch.

Code	25	26	27	28	29	30	31	32	33	34	35	36
Size	C	C	C	C	C	C	C	B	B	D	E	F
	1	2	3	4	5	6	7	7A	7B	27	28	29

All this variables are read from an external source and then are linked to the model considering the descriptions presented so that the simulation model reads the information of the flights to be generated and their characteristics and takes into consideration the operational restrictions of the process.

6 RESULTS AND DISCUSSION

As stated earlier, solving the sizing bus fleet problem requires a simulation model due to the complexity of the problem and the high number of stochastics variables involved and different scenario conditions regarding bus movement within an airport. Given this restriction, the aim is to achieve a greater degree of efficiency and reliability to be able to solidly accomplish the standard operation times needed by international regulations. The built simulation model allows to make changes in the size of the bus fleet and measure the impact of these modifications on the main indicators of the process. Therefore, with the objective of determining the optimum number of buses the following procedure was followed:

1. The fleet size was started in the current amount of 12 available buses
2. Proceed to run the model and calculate from the bus usage meters the number of average bus requirements per hour of the day. This was decided because it was observed that although there are periods in which the current buses are insufficient, this occurs only in the peak periods of operation of the IA.
3. If it is determined that the peak is equivalent to the float size, the procedure is repeated, increasing the fleet size by one unit and returning to step 2.

The analysis was started with a fleet size of 12 units and it was completed with 17 units, because at that point all the peaks were below the size of the fleet. Increasing the fleet size further from 17 units will probably give better overall utilization results however the airport wanted to determine the minimum fleet size that satisfied a waiting time under the standard waiting time of 5 minutes per flight so the cost investment in new bused was also the minimum possible due to budget operation restrictions. This is the main reason why also an opportunity cost related to waiting time of passengers wasn´t take into account.

It is observed that the peak period of operation where more buses on average are required is between 8 and 10 in the morning where the average values are 16.1, 16.4 and 16.3 respectively. Based on this evidence, the fleet size recommended in these intervals would only be 17. It should be mentioned that within the final scenarios studied were included preventive and corrective maintenance periods for the vehicles, adding fault information presented to ensure that the technical feasibility of the results are as accurate as possible in the environment of the application of the obtained recommendations.

In summary, for the fleet level of 17 buses, the following average service times of the bus system are available (reference is made from when the bus is requested until the last group of passengers on the flight ends up being served by the last bus assigned) that are detailed by type of movement in Table 5.

Table 5: Average bus transportation time per flight and type.

Indicator	Time in minutes	Flow	Type
Total Bus Transportation Time per Flight	11.25	Arrival	National
	11.85		International
	12.68	Departure	National
	15.39		International

These times correspond to acceptable average values within the operating range defined by the airport administrator. Under these results, it is also possible to ensure waiting times for the start of operation below the critical limits defined in the conceptualization of the problem. The results obtained consider a projected operating horizon of up to 5 years, at which time the historical data of the model built based on new data available for capacity planning of the next operating period must be updated based on the operational changes that are made. can present in the very logic of the loading and unloading operation.

The bus fleet sizing problem was effectively approached with the use of the simulation model since all the process constraints and conditions were declared and handled by the model when the scenarios were analyzed. The simulation model and later on scenarios are an effective way to try different changing conditions and allow to include the stochastic variables in the boarding and disembarking process. The results obtained give service times within the international standards which allows the international airport to effective deal with the bus service shortage and proves to reduce drastically the number of delayed flights due to bus capacity problems. This work can be extended to include this airport sub model into another yet more complex and comprehensive simulation model of airport operations due to the flexibility of adjustment of the model capacity to read external data to reflect different fluctuating conditions that can be expected to be found in other similar international airports.

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