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WARNINGS ABOUT SIMULATION REVISITED: IMPROVING OPERATIONS IN CONGONHAS AIRPORT

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ABSTRACT

This paper highlights some of the primary concerns about simulation recently raised by academics and practitioners. These concerns influenced the creation of a successful simulation project that improves the check-in at Congonhas Airport in São Paulo, Brazil. Use of simulation was essential in Congonhas because, although significant growth in the number of passengers has occurred over the last decades, Congonhas has limited capacity for expansion due to its location. Two major airlines, which represent 88% of the market share of Congonhas, were considered in this study. Output results demonstrated that a majority of future customers will experience excessive wait times to check in. Therefore, improvement scenarios were proposed in order to meet comfort levels required by international organizations.

1 INTRODUCTION

Many academics and practitioners have recently discussed concerns about simulation that can potentially cause failure of a simulation project. These concerns and subsequent warnings have helped the simulation community avoid critical pitfalls, which results in more accurate simulation projects. This paper discusses many issues summarized by Banks and Chwif (2010) from an application perspective and highlights their contributions to a successful simulation project. Moreover, the problem emphasized in this paper is of great concern to many developing countries with saturated airports, particularly Brazil. The paper also presents recommendations to adjust the time customers wait in line to check in with standard comfort levels determined by international organizations.

In the last decades, transportation customers worldwide have begun to more frequently utilize flight transportation instead of rail or road transportation, thereby significantly increasing usage of the airline industry. This significant growth can also be attributed to a decrease in airfare during this period. Many developing countries such as Brazil have also experienced increasing economies, allowing people from low economic classes to utilize this expeditious mode of transportation. Consequently, airports require significant financial investments in order to meet standard comfort levels and avoid delays in this complex

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transportation system. Many airports in Brazil operate with limited infrastructure; however, this situation has begun to change in the last four years due to Brazil's hosting of major events such as the FIFA World Cup 2014 and the Rio 2016 Olympic Games. Although some infrastructure investments have been made to support these events, the improvements are not sufficient long-term investments because the increasing number of passengers is outpacing the amount of investments (McKinsey & Company 2010).

Congonhas Airport is considered the business airport of Brazil because it is located in the main urban area of São Paulo. In contrast to other airports, Congonhas has limited capacity for expansion, and construction of new landing areas, passenger terminals, or control towers is infeasible. However, flight transportation through Congonhas has increased considerably, making resources such as check-in and security check areas insufficient to meet all passenger demands. The discrete event simulation model developed for this paper considers the check-in of two major airline companies at Congonhas Airport, which represent 88% of the total market share of this airport. In order to remain anonymous, airlines are identified in this paper as Company A and Company B.

The remainder of the paper is organized as follows. Section 2 provides a brief literature review with background information, recent conclusions of warnings about simulation, and evidences that justify the use of simulation to improve the check-in area at Congonhas Airport. Sections 3, 4, and 5 present the development of the simulation project according to suggestions summarized by Banks and Chwif (2010). Section 6 concludes the paper and provides topics for future research.

2 LITERATURE REVIEW

2.1 Warnings and Pitfalls in Simulation Projects

Suggested studies that address concerns and pitfalls of simulation include Barth et al. (2012) and Williams and Ülgen (2012). Banks and Chwif (2010) also summarize many warnings from the literature and provide reasonable suggestions according to their professional experience. They divide these warnings into seven categories: data collection, model building, verification and validation, analysis, simulation graphics, management of the simulation process, and human factors, knowledge, and abilities. The pitfalls for each category are described below and many of them are approached throughout this paper.

For data collection, Banks and Chwif (2010) discuss quality and amount of input data, selection of the wrong statistical distribution, up time instead of time between breakdowns, and the data acquisition process. For model building, they suggest constructing a proper model (not too simple, not too complex), creating a conceptual model prior to implementation, and validating the computational model gradually. Banks and Chwif (2010) also make relevant contributions with various techniques in order to verify and validate conceptual and computational models. For analysis, Banks and Chwif (2010) promote not simulating output data, avoiding point estimates, determining warm-up periods, and having appropriate performance measures for comparison. They also recommend that practitioners avoid being impressed by fancy graphics but instead organize models properly so viewers can readily understand the simulation model. Regarding management of the simulation process, the authors encourage practitioners working on simulation projects to follow principles from project management, to clearly define the objective of the study, to not overestimate the power of simulation, and to not cut off phases of the simulation modeling process. Banks and Chwif (2010) conclude by asserting the importance of statistics, spreadsheet skills, and "humanware".

2.2 Airline Industry Worldwide and in Brazil

The volume of airline passengers worldwide is measured by the revenue passenger kilometers index, which has increased more than 10 times since 1970, making the airline industry one of the fastest growing industries (IATA 2011). Currently, 43% of passengers travel between the United States, Canada, Western Europe, and Japan; however, this percentage is expected to decrease in 2030 when 70% of the airline traffic will occur in other countries around the globe (Airbus 2011). Furthermore, the airline industry in Latin America is expected to increase 7.2% per year until 2030, just 0.3% behind China (Embraer 2011). The reason for such a drastic increase in the airline industry is a 60% decrease in the cost of air transportation since 1970 due to increased efficiency of new aircrafts, more efficient utilization of airplane fleets, and improved performance of airline companies. All of these factors have caused airfare to decrease at the same rate of air transportation costs (IATA 2011).

Airfare in Brazil decreased 70% from 2002 to 2015 (ANAC 2016), and gross domestic product (GDP) increased 11% per year, on average, from 2001 to 2015 (IBGE 2016). Domestic flight traffic in Brazil is expected to be the 15$^{\text{th}}$ largest in the world by 2030, increasing at a rate of 6.6% per year. Moreover, 25% of total international travel in Latin America occurs in two major airports of Brazil: the International Airport of São Paulo and the International Airport of Rio de Janeiro. Overall, 9.1% of the GDP in Brazil originates from tourism and business travel, which generate approximately 8 million jobs (Airbus 2011).

2.3 Airports in São Paulo and the Congonhas Airport

Three major airports in Brazil are located in São Paulo. The International Airport of São Paulo (GRU) can currently handle 42 million passengers per year. In 2015 GRU was the busiest airport in Brazil with almost 39 million passengers. The Airport of São Paulo - Congonhas (CGH) was the third busiest airport in Brazil in 2015 with more than 19 million passengers and capacity for 17 million, while the International Airport of Viracopos (VCP) was the sixth busiest airport in Brazil with more than 10 million passengers and capacity for 10 million passengers (Infraero 2016b).

The state of São Paulo has become the hub of air transportation in Brazil because São Paulo has the highest GDP in Brazil and Latin America and is expected to have the sixth highest GDP in the world by 2025 (PWC 2009). In addition, many industries and financial companies are located in São Paulo and its metropolitan area, making the state of São Paulo the most powerful state in Brazil. In 2015 GRU, CGH, and VCP combined accommodated approximately 26% of the total number of aircraft in Brazil, 28% of the total number of passengers, 32% total cargo transportation, and 38% total postal mail (Infraero 2016b).

Current flight traffic in CGH averages 585 movements per day, including takeoffs and landings (Infraero 2016a). In contrast with GRU and VCP, which have received recent investments for the FIFA World Cup 2014 (although both airports currently operate close to capacity), CGH has received less investments due to its limited capacity for expansion. Any growth in both runway systems and passenger terminals is infeasible at CGH (McKinsey & Company 2010, Santana et al. 2006). Although CGH handles only domestic flights, the number of CGH passengers increased 58% from 2003 to 2015 (Infraero 2016b). Furthermore, check-in and security check areas in CGH are fully saturated and operating at 159% and 130%, respectively, over capacity (McKinsey & Company 2010).

2.4 Airport Passenger Terminals

An airport is typically divided into landside and airside zones. The landside area contains the passenger terminal, parking lots, and public transport railway/road stations. The airside area includes runways, taxiways, and ramps. An airport passenger terminal includes all passenger service facilities, including airline stores, check-in, departure and arrival halls, baggage claim areas, security check areas, and immigration services (Medau 2009). A passenger terminal is divided by flow (departure, arrival, connection) or segment (domestic or international) (McKinsey & Company 2010).

The service level of an airport passenger terminal is generally measured by the number of customers in the system in comparison with the number of customers the system can process with a given comfort level (McKinsey & Company 2010). This service level represents how close the passenger terminal is to operating capacity. In order to determine whether improvements should be made, this service level must be compared to national (e.g., Infraero) or international (e.g., International Air Transport Association (IATA)) standards. For instance, IATA recommends that airports operate at a service level in which passengers do not wait more than 12 minutes in line. IATA also states that wait times between 12 and 30 minutes are too long and delays over 30 minutes are unacceptable (IATA 2014).

2.5 Simulation in Airports

Discrete event simulation, which efficiently models systems in which changes occur in discrete moments from the occurrence of an event, is a prominent tool in the decision-making process for airports or other systems requiring resources. Many authors have suggested and applied simulation to manage resources in airports. Takakuwa and Oyama (2003) developed a simulation model with Arena® to evaluate international arrivals and departures at the International Airport of Kansai in Japan. Appelt et al. (2007) used Arena® to simulate the check-in procedure at the Buffalo Niagara International Airport in USA. Kontoyiannakis et al. (2009) presents a simulation-based model that evaluates gate allocation polices under reduced runway capacity at the Detroit/Wayne County Airport in USA. Fioroni et al. (2013) utilized Arena® to address the soil replacement project at the International Airport of São Paulo (GRU) as part of the airport expansion.

3 CONCEPTUAL DESIGN

The overall simulation study was accomplished within one year and was divided into conceptual, implementation, and analysis design (Chwif and Medina 2014). This section presents the main steps followed during the conceptual design while implementation and analysis design are described in the following subsequent sections. The simulation project schedule was presented and approved by both airlines. Managers, supervisors, leaders, and analysts of both airlines were involved in all phases of the study as suggested by Banks and Chwif (2010). These professionals were critical in order to avoid Type III error (when a solution is developed to the wrong problem). Due to the limited number of pages, only the most relevant results are presented in this paper, but Vitor and Santos (2012) include all results obtained in this simulation study.

3.1 Conceptual Model

As suggested by Banks and Chwif (2010), a conceptual model was built before the computational model was implemented. This model was crucial for this project because it helped the authors understand the check-in process at Congonhas Airport. This simulation study considered six classes of check-in offered by Company A and Company B: regular, baggage drop, self-service, air shuttle, priority, and loyalty check-in. Passengers initially choose between web or self-service check-in and then proceed to the baggage drop queue if they have checked baggage. If a passenger does not use the web or self-service check-in, he/she proceeds to the priority, loyalty, air shuttle, or regular queue. Regular check-in is reserved for customers who are unable to use priority, loyalty, or air shuttle check-in. Figures 1 and 2 present the activity cycle diagrams (ACDs) used to conceptually model this system.

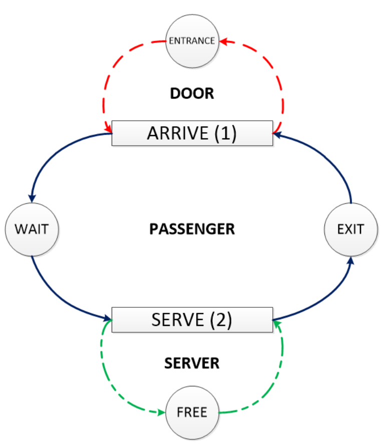

Figure 1: ACD: Air Shuttle, Loyalty, Priority, and Regular Check-In.

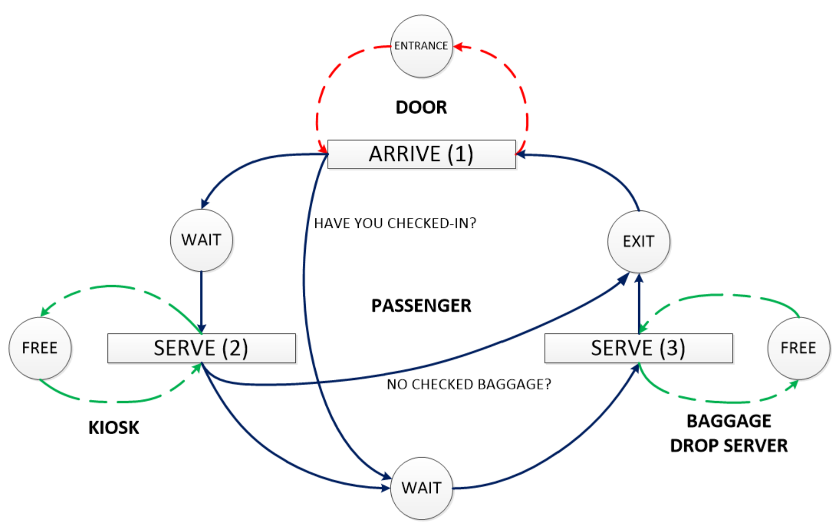

Figure 2: ACD: Baggage Drop and Self-Service Check-In.

3.2 Input Data, Output Results, and Assumptions

Banks and Chwif (2010) recommend defining input data properly. The primary input data acquired for both airlines based on interviews and time measurement were: passenger arrival time before flight takeoff, service time for each class of check-in, employee's schedule for each class of check-in, load factor (occupancy level) for scheduled flights, percentage of customers served by each class of check-in, and percentage of customers who checked-in in groups. Other relevant input data acquired included the reason for travel, gender, age, travel destination, and opinions/suggestions regarding airline service.

Another relevant concern raised by Banks and Chwif (2010) is related to defining output data and assumptions correctly. Output data required for analysis in this paper included: percentage of customers waiting in line less than 12 minutes, percentage of customers waiting between 12 and 30 minutes, percentage of customers waiting longer than 30 minutes, and average waiting time in queue for each class of check-in. This study also considered service delays due to shift change or breakdowns in baggage claim carousels. These times were initially not considered but primary results indicated that these factors significantly impact output results as explained by Chwif et al. (2015). In addition, measured service time already considered employee performance and passenger travel times between the queue and the counter.

3.3 Data Acquisition

Banks and Chwif (2010) also raise concerns about anticipating problems with input data and accurately acquiring sufficient data. The randomness in the check-in area at Congonhas Airport is relatively high and acquiring a small amount of input data would definitely lead this project to incorrect recommendations. After careful discussion of these problems with both airlines, the authors decided to acquire data for this work from April though July in three periods (morning, afternoon, and night) with three demands (low, medium, and high) for each class of check-in. Data was also acquired during holidays and vacation periods to account for possible differences in demand. Data acquisition adhered to the following process:

- A sequence of random consecutive flights was chosen for each period of the day such that the difference between takeoff times of the first and last flights in this list were approximately 4 hours;
- Data acquisition began 2 hours before the takeoff time of the first flight and ended 30 minutes before the takeoff time of the last flight;
- Consequently, only data from passengers belonging to flights on this list was acquired, implying that any passenger checking in for a flight not on the list was not considered.

On average, 25 flights were considered in each acquisition for each period of the day, and more than 220 hours of data were acquired during four months. Note that acquiring such amount of input data simplified the validation process discussed in Section 4.1.

3.4 Input Data Analysis

Another relevant warning by Banks and Chwif (2010) pertains to choosing incorrect input distributions. In order to guarantee that input distribution appropriately represents input data, this data was analyzed in Minitab® and Stat::Fit®. The first step to analyze the data after removing all outliers included an analysis of variance (ANOVA) to determine whether information from low, medium, or high demand were statistically equal and could be merged. For instance, no evidences prompted rejection of the normality, independence, and constant variance assumptions with 95% confidence for passenger arrival time and service time of regular check-in of Company B. However, results revealed evidences to reject the hypothesis that all three means (low, medium, and high) were equal for arrival time and no evidences to reject this hypothesis for service time with 95% confidence. Consequently, data for passenger arrival time could not be merged, but data for service time could be merged.

The data was independent for passenger arrival time and service time, and the correlation was weak enough to be considered. Figures 3 and 4 show histograms for passenger arrival time with low demand (minutes) and service time merged (seconds), respectively. Based on Kolmogorov-Smirnov and Anderson-Darling tests, in low demand periods passengers arrive in regular check-in of Company B according to a Gamma distribution with $min = 27$, $\alpha = 4.07$, and $\beta = 14.5$, and they are served in this check-in in any demand period according to a Pearson 6 distribution with $min = 42$, $\beta = 2.31 \times 10^4$, $p = 1.91$, and $q = 409$.

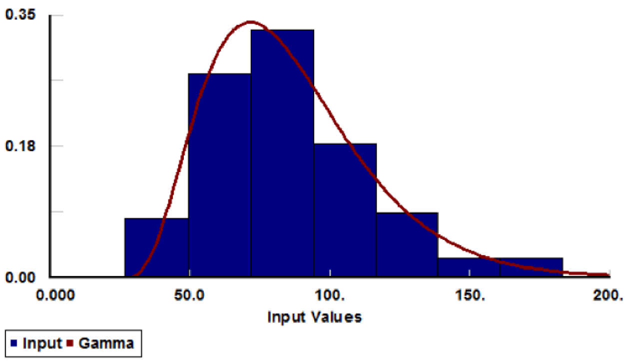

Figure 3: Histogram of Arrival Time.

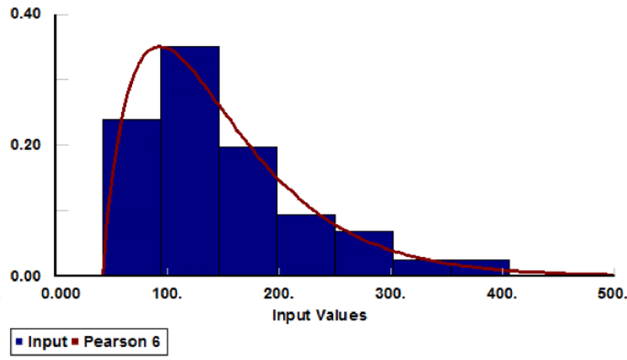

Figure 4: Histogram of Service Time.

4 IMPLEMENTATION DESIGN

During implementation design the authors created a computational model that is complex enough to represent the system described in Figures 1 and 2 as suggested by Banks and Chwif (2010). This computational model was implemented gradually: each class of check-in was implemented and validated separately prior to merging all models, as recommended by Banks and Chwif (2010). Simulation software used in this project was SIMUL8®. Figure 5 presents the computational model developed for Company A, where (A) is loyalty, (B) is baggage drop, (C) is priority, (D) is air shuttle, (E) is regular, and (F) is self-service check-in. For each check-in, passengers arrive in the queue and wait until a counter is available. Passengers are then served and leave the system when service is completed. All connector lines are hidden for easier visualization. The computational model for Company B follows the same process.

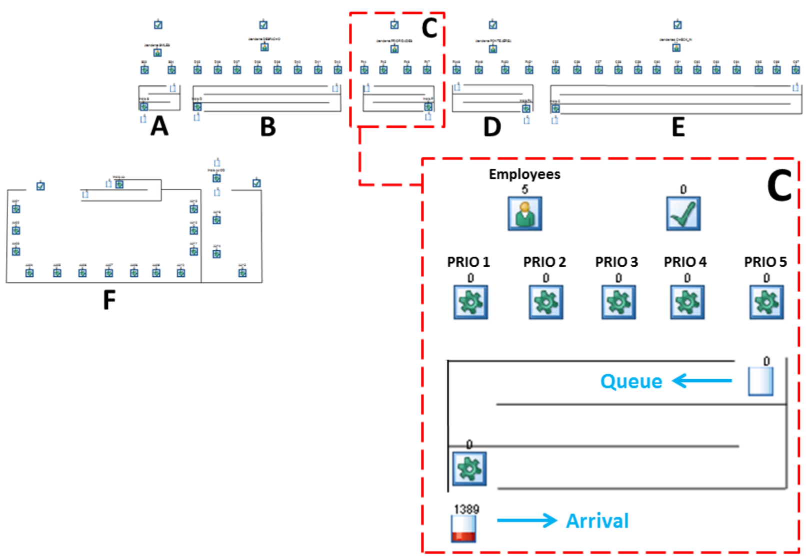

Figure 5: Computational Model.

In order to determine service time, counter availability, and number of customers in each class of check-in, distributions provided in Section 3.4, employee schedules for each shift and day of the week, and percentage of customers served by each class of check-in can be inputted into the computational model; however, a more complex procedure is required to determine the arrival process. Figure 6 shows an example of only one flight departing every hour starting at 9:00 a.m. and ending at 4:00 p.m. As described in Section 3.3, passengers begin arriving 2 hours before takeoff time and stop arriving 30 minutes before takeoff time. If passenger arrival time before flight takeoff follows a Gamma distribution, as concluded from Section 3.4, then the total number of passengers scheduled for a 9:00 a.m. flight begin arriving at 7:00 a.m. according to the Gamma distribution in blue. Passengers for a 10:00 a.m. flight begin arriving at 8:00 a.m. according to the Gamma distribution in red. This process follows from the first until the last flight scheduled. Note that between 8:00 a.m. and 8:30 a.m. passengers from both flights overlap.

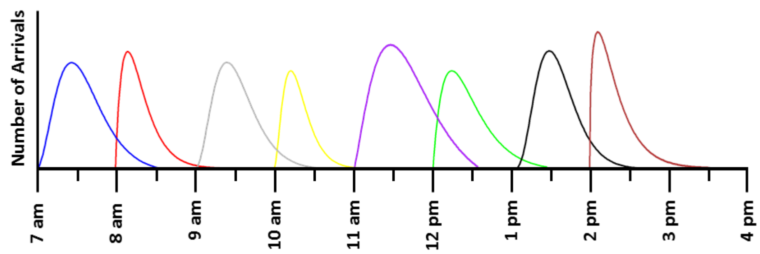

Figure 6: Passenger Arrival Scheme.

In this example, the number of overlapping passengers from different flights is small because only one flight per hour is considered. However, in an airport such as Congonhas, which hosts an average of 34 takeoffs per hour, this overlapping period may result in long queues. Although the algorithm developed in SIMUL8® for this procedure is not presented in this paper, the input to the algorithm is a list with all flights scheduled for each day and the load factor for each correspondent flight.

4.1 Base Model's Verification and Validation

Banks and Chwif (2010) highly recommend practitioners "to do a lot of verification, not too little." Therefore, the computational model in this study was verified via modular verification, graphical animation, and team revision methods (Chwif and Medina 2014). All three methods were used simultaneously with model construction. In order to validate the computational model, output results obtained with the acquired input data were presented to managers, supervisors, leaders, and analysts of both airlines. The authors met these professionals at least three times until all minor problems have been solved. Such problems basically included high/low average wait times for air shuttle, priority, regular and baggage drop check-in.

The major challenge encountered in the validation process was to find reasonable changes regarding input data that would lead to a more realistic computational model given the randomness in the check-in area at Congonhas Airport is high. The main changes during the validation included increasing/decreasing the number of passengers arriving in air shuttle, priority, and regular check-in of Company A, decreasing the number of passengers arriving in priority check-in of Company B, and increasing the number of resources available in baggage drop queue of Company B. These changes were correctly implemented and the computational model was then validated.

5 ANALYSIS DESIGN

Banks and Chwif (2010) also describe many pitfalls that should be avoided in the analysis of a simulation project. First, this project did not consider a warm-up period because Congonhas is a terminating system. The study evaluated the airport in operation for 18 hours (5:00 a.m. to 11:00 p.m.) every day of the week (Monday to Sunday). Both airlines operated in three shifts (5:00 a.m. to 11:00 a.m., 11:00 a.m. to

5:00 p.m., and 5:00 p.m. to 11:00 p.m.). Second, the computational model in this study simulated all outputs described in Section 3.2, and performance measures were defined according to recommendations of IATA (Section 2.4) because Congonhas Airport is not a "push" system. Banks and Chwif (2010) also recommend avoiding point estimates, so the number of replications for this study was determined via $n^* = n\left(\frac{h}{h^*}\right)^2$, where n is the sample size, h is the precision of the sample size, h^* is the desired precision, and n^* is the required number of replications to achieve h^*. This study determined a precision of $h^* = 0.5$ minute for average waiting time in queue. Consequently, $n^* = 87$ replications were required. For simplicity, every trial performed in the analysis design ran 100 replications, thereby achieving the determined precision.

5.1 Base Model Results for Current and Future Demand

The first step in evaluating results for future demand is to calculate increase of the current demand for future years. According to the number of passengers flying from/to Congonhas Airport between 2003 and 2015, an average increase of 4.2% per year was determined via a linear regression model. However, this growth would result in many scheduled flights exceeding maximum capacity in future years. Therefore, all results presented in this paper for future demand considered flights with a maximum 100% load factor. Figures 7 and 8 present waiting times in queue for regular check-in of Company A and Company B, respectively. These figures show simulations of the current demand from 5:00 a.m. to 11:00 p.m. for four rush days in May. Figures 9 and 10 present waiting times in queue for regular check-in of Company A and Company B, respectively, for future demand for five rush days.

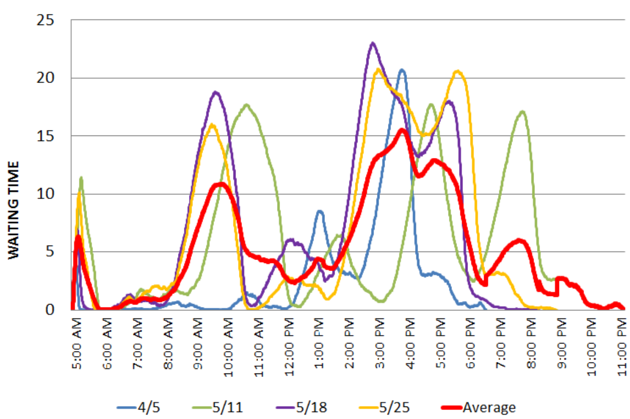

Figure 7: Current Demand of Company A.

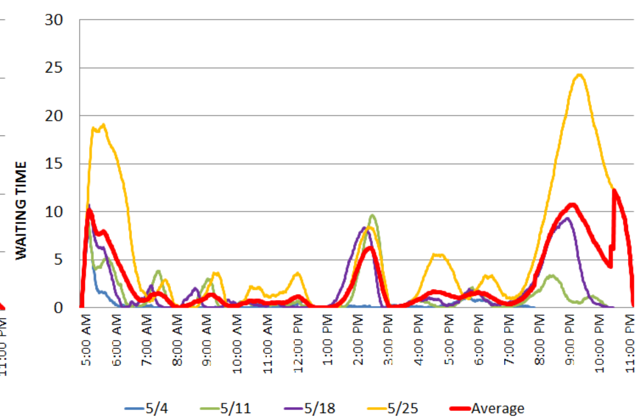

Figure 8: Current Demand of Company B.

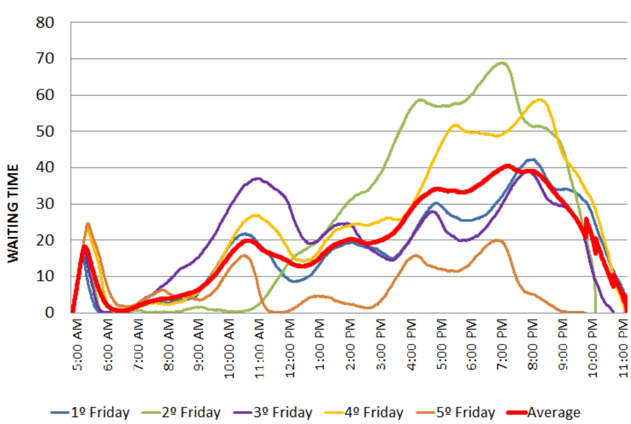

Figure 9: Future Demand of Company A.

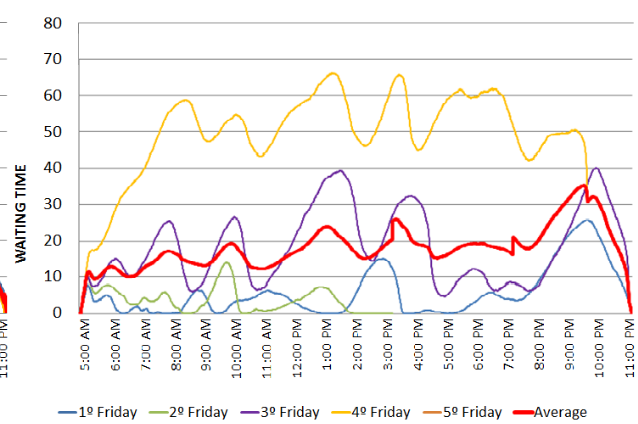

Figure 10: Future Demand of Company B.

On average, 81.7% of customers wait less than 12 minutes, and 18.3% wait between 12 and 30 minutes in regular check-in of Company A. For future demand, 38.3% of customers would wait less than 12 minutes, 38.7% would wait between 12 and 30 minutes, and 23.0% would wait more than 30 minutes in line. For Company B, 95.1% of customers wait less than 12 minutes and 4.9% wait between 12 and 30 minutes. For future demand, 58.8% would wait less than 12 minutes, 17.2% would wait between 12 and 30 minutes, and 24.0% would wait more than 30 minutes. Table 1 summarizes the results for all other classes of check-in. Note that a considerably number of customers of both airlines currently wait too long in line according to the standards of IATA (Section 2.4). This situation is expected to worsen for future demand when an increased percentage of customers would wait too long in line and another percentage would wait an unacceptable amount of time. Consequently, this paper also presents improvement scenarios to help both airlines manage this system with an infrastructure-constrained growth demand.

Table 1: Percentage of Waiting Passengers.

		Current Demand			**Future Demand**		
		<12	$12-30$	>30	<12	$12-30$	>30
Company A	**Regular**	81.7%	18.3%	0.0%	38.3%	38.7%	23.0%
	Baggage Drop	89.8%	10.2%	0.0%	56.9%	35.1%	8.0%
	Self-Service	99.0%	1.0%	0.0%	51.5%	23.3%	25.1%
	Air Shuttle	89.3%	10.7%	0.0%	39.7%	16.8%	43.5%
	Priority	90.1%	9.4%	0.5%	84.3%	15.7%	0.0%
	Loyalty	76.4%	23.6%	0.0%	57.6%	36.9%	5.4%
Company B	**Regular**	95.1%	4.9%	0.0%	58.8%	17.2%	24.0%
	Baggage Drop	99.0%	1.0%	0.0%	57.4%	21.1%	21.5%
	Self-Service	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
	Air Shuttle	99.6%	0.4%	0.0%	96.9%	3.1%	0.0%
	Priority	100.0%	0.0%	0.0%	56.9%	21.1%	22.0%
	Loyalty	99.5%	0.5%	0.0%	96.8%	3.2%	0.0%

5.2 Improvement Scenarios

In order to serve a majority of future customers within less than 12 minutes, the following are proposed:

1. Addition of one regular, air shuttle, and loyalty check-in counter, two baggage drop check-in counters, and two self-service kiosks for Company A; addition of one loyalty check-in counter, two regular check-in counters, and three baggage drop check-in counters for Company B;
2. Split of regular and baggage drop queues based on flight destinations;
3. Increase of 10%-20% use of web and self-service check-in as a result of an efficient marketing campaign and improved utilization of filter lines;
4. Merging of regular and baggage drop queues;
5. Removal of all passengers with no baggage to check from regular, baggage drop, air shuttle, priority, and loyalty queues, and assignment of these passengers into self-service check-in queue;
6. Creation of a new queue for customers with excess baggage, requiring six counters for Company A and five counters for Company B;
7. Split of regular and baggage drop queues based on the amount of baggage per passenger;
8. Use of tablets in regular check-in queue, in which an airline employee would input required information into the system (name, travel destination, number of baggage to check, emergency contact, etc.) while passengers still wait in line so that when customers arrive at the counter the only remaining operations are tagging and checking the baggage and printing the boarding pass;

9. Removal of all passengers with baggage to check from self-service queue and assignment of these passengers into regular, air shuttle, priority, or loyalty queues, while also removing all passengers with no baggage to check from regular, baggage drop, air shuttle, priority, and loyalty queues and assignment of these passengers into self-service queue, resulting in only web check-in customers with baggage to check at the baggage drop queue;
10. Combination of Scenarios 1 and 3, in which Company A must add three self-service kiosks and Company B must add five baggage drop check-in counters;
11. Combination of Scenarios 1, 3, and 6, in which Company A must add three self-service kiosks and assign seven counters for customers with excess baggage, while Company B must add one regular check-in counter, two baggage drop check-in counters, and assign three counters for the new queue;
12. Combination of Scenarios 1, 3, 5, and 8, in which Company A must add six self-service kiosks, and Company B must add two baggage drop check-in counters.

All scenarios that require the addition of new counters/kiosks utilize existing unused counters or existing free spaces in the airport to allocate required equipment. Some of these scenarios also require that all existing counters be fully operated, resulting in the gradual hire of additional employees. Scenarios 1, 6, 8, 9, 10, 11, and 12 result in 98% of customers from Company A waiting less than 12 minutes in line, on average, while Scenarios 1, 5, 6, 7, 8, 9, 10, 11, and 12 result in 99% of customers from Company B waiting less than 12 minutes in line, on average. Scenario 3 results in 15% of customers waiting between 12 and 30 minutes and 52% of customers waiting longer than 30 minutes, on average, in baggage drop queues for both airlines. Scenarios 2 and 4 were considered unsatisfactory for both companies since several customers would wait longer than 12 minutes in line. Scenario 5 results in 19% of passengers waiting between 12 and 30 minutes and 47% of passengers waiting more than 30 minutes, on average, in self-service queue of Company A. Scenario 7 results in 23% of customers from Company A waiting between 12 and 30 minutes and 24% of customers waiting longer than 30 minutes, on average, for all classes of check-in.

5.3 Recommendations

Many improvement scenarios demonstrated potential for decreasing the number of passengers waiting in line more than 12 minutes for both airlines. In order to determine which scenario(s) provide the best benefit-cost ratio, all implementation costs of each scenario must be considered. Therefore, this study estimated the costs of adding new counters/kiosks, increasing the number of employees, purchasing new equipment, and implementing new visualization systems. Such estimations were made with the collaboration of both airline companies but cannot be described in this paper due to confidentiality reasons. Scenario 12 provides the highest benefit-cost ratio for Company A and Company B. Therefore, the authors recommend that both airlines begin using a new data acquisition process that utilizes tablets integrated into each airline's system, increase the use of web and self-service check-in by 10% to 20%, and begin removing all passengers with no checked baggage from regular, baggage drop, air shuttle, priority, and loyalty queues and assign these passengers into self-service check-in queue. In addition, Company A must add six self-service kiosks and Company B must add two baggage drop check-in counters.

6 CONCLUSIONS AND FUTURE WORK

This work presented some of the primary simulation concerns that were used to successfully create a simulation project from conceptual to analysis design. Many of these warnings were essential to complete all phases of this project because they helped construct a reliable model to evaluate the check-in area at Congonhas Airport. These concerns also helped provide efficient solutions to improve check-in at both airlines in this study, always considering the limited capacity for expansion of Congonhas Airport.

Three warnings deserve attention in this conclusion. First, frequent interaction with employees during the entire project was crucial because these professionals contributed with appropriate knowledge and information about the system. Second, choosing distributions that were statistically significant for arrival and service time was essential to accurately represent this complex operational system. The authors attempted to use empirical distributions, but these failed during validation. In addition, ignoring delays due to shift change or breakdowns in baggage claim carousels was an incorrect decision. When correctly implemented, delay and breakdown times helped validate the computational model. Third, if one was to forecast future demand without assuming the capacity for scheduled flights, then all conclusions would be incorrect and improvements scenarios would consider higher implementation costs.

In order to continue improving operations at Congonhas, the methodology demonstrated in this paper could be used to evaluate other areas in the airport such as departure and arrival halls, baggage claim areas, runways, and taxiways. Simulation of departure/arrival halls and baggage claim areas is similar to the one presented in this paper because passenger arrival time is in some way related to the time of the flight these passengers belong. Furthermore, acquiring input data to simulate runways and taxiways is easily achievable because not only Congonhas but every airport worldwide exactly track this information. Future research could also incorporate events not considered in this work, such as cancelled flights and charter flights, and also determine an optimal schedule for employees to avoid idle or overloaded workers.

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