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SIMULATION REDUCES AIRLINE MISCONNECTIONS: A CASE STUDY

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ABSTRACT

With most major airlines operating a hub-and-spoke system and partnering with other airlines to offer code share flights, more and more passengers are required to make at least one connection before reaching their final destination. These trends in the airline industry have increased the percentage of transfer passengers. In order to minimize the number of missed connections and offer customers a seamless journey, airlines must maintain time limits in which domestic and international transfer passengers can reach their connecting gates at the airports. This paper focuses on how simulation is used to evaluate an airline's minimum connect time criteria with respect to the design and operational policies at its hub airports. We consider a case study of Delta Air Lines' new planned state-of-the-art facility at John F. Kennedy International Airport to illustrate the significant role simulation played in the planning stages of an airport design.

1 INTRODUCTION

Most of the major passenger airlines use a hub-and-spoke network to route their aircraft. A hub is a central airport that aircraft are routed through, and spokes are other airports that feed into and out of the hub airport. Hubs allow the airlines to offer more flights to more destinations at lower costs. After the federal government deregulated the airlines in the late 1970's, the hub-and-spoke system has become a common practice for most major airlines. Before deregulation, many flights operated with a significant number of unoccupied seats, especially between two small markets. This was a result of the direct-route or point-to-point system that the government enforced airlines to use prior to deregulation. This point-to-point route structure caused airlines higher costs. Most airlines operate today with at least one hub airport which routes passengers to their destination cities. Delta Air Lines (DL), which has its major hub at Hartsfield Atlanta International Airport, is a good example of how a hub-and-spoke system operates. A passenger traveling from Birmingham, AL to Baltimore, MD on DL would fly from Birmingham to Atlanta, and then from Atlanta to Baltimore. This is due to the relatively small passenger demand for a Birmingham to Baltimore flight.

The main advantages of a hub-and-spoke system are:

- The demand of many city pairs can be served with significantly fewer aircraft,
- Economies arise from concentrating more passengers on larger aircraft,
- Maintenance facilities can be easily centralized, and
- Crew bases can be limited to the hub airports.

On the other hand, the main disadvantages of a hub-and-spoke system are:

- Extra stops for passengers at hubs,
- Peaking at hub airports that adversely affects capacity, congestion, and resource utilization,
- Delays associated with localized weather patterns impacting the overall system performance, and
- Cost of accommodating passengers who miss their flights.

Code-sharing is a marketing arrangement between airlines in which one of the airlines places its designator code on a flight operated by the other airline, and sells and issues tickets for that flight. Airlines throughout the world continue to form code-share alliances to expand their market presence and gain competitive advantage.

With most major airlines operating under the hub-and-spoke system and offering code-share flights, an enormous increase in the number of transfer passengers has occurred due to connecting flights and code share agreements. This increase creates the need for determining the required minimum connect time between two consecutive flights in a passenger itinerary. This minimum connect time is then used in generating possible routes for the reservations system. It is important that minimum connect times are established in a manner that provides passengers adequate time to make their connecting flights. When a transfer passenger misses a flight, the airline usually accommodates the passenger on the next available flight. If the passenger misses the last flight of the day, the airline usually provides accommodations at a nearby airport hotel and pays for certain expenses (e.g., meals and lodging) only when delay is not weather related (i.e. delay due to airline performance). Therefore, there are direct costs associated with passenger misconnections as well as indirect costs such as loss of goodwill.

Hafizogullari et al. (2001) described a project about the analysis of vehicular and passenger handling at a new airport terminal to be constructed. Simulation was applied to evaluate the ability of the new terminal to accommodate the projected passenger demand such that the performance objectives were achieved. Kiran et al. (2001) constructed simulation models for a new international airport. The simulation models helped evaluate passenger and aircraft flow from the terminal entrance to boarding; identify the system bottlenecks as well as the system capabilities. Gatersleben et al. (1999) have applied simulation to gain insights into the relations between the distinguished processes, the presence of bottlenecks, and their causes to redesign the passenger handling at an airport.

This paper focuses on the methodology that was used to determine the minimum connect times at an airport terminal. Simulation was used as a tool to predict passenger travel times within the airport terminals and to determine passenger wait times at various processing points. A case study for DL terminals at John F. Kennedy Airport (JFK) is presented.

2 APPROACH

Accurately modeling the operation of a real-world process over time, such as the flow of passengers through an airport, can result in problems of immense magnitude and complexity. Although many operations research techniques such as linear/integer programming, stochastic programming, and queuing theory provide valuable insights, they often fail to represent large-scale problems that arise in airport terminal design due to poor scalability or excessive computational burden. We use simulation modeling to represent operations in a terminal building because of its ability to capture complex relationships and scalability. The processes at an airport are interdependent. Separate modeling and optimization of individual components may result in sub-optimal solutions. Simulation addresses this problem by quantifying the interdependencies and finding bottlenecks. Solving one bottleneck may cause another bottleneck to develop somewhere else in the system and the modeler needs to consider the total system performance.

This paper focuses on the use of discrete event simulation to model transfer passenger flow in an airport. The simulation model accounts for the architectural design of the proposed facility with a detailed depiction of the terminal geometry, and mimics the passenger and inbound baggage flow throughout the terminals. A variety of objectives can be considered such as:

- Minimize the average passenger travel time between the arrival and the departure gate,
- Minimize the maximum (or desired percentile) passenger wait time in terminals, and
- Minimize the number of passengers who do not meet the minimum connect time criteria.

These are only a few examples of objectives that can be used to select a terminal design that will be the most suitable for a hub airport. These objectives are subject to certain constraints imposed by the airlines and airport authorities such as space, budget, and staffing levels as well as maintaining desired performance standards of service and congestion.

The initial step of the modeling exercise is to develop an assumptions document that includes key process data and operational procedures. The required data can be classified into two categories: passenger behavior and terminal processing. This information is typically gathered via airline/airport personnel interviews, on-site data collection and surveys, and historical data available via public sources such as Federal Aviation Administration (FAA) and airport web pages.

The typical passenger data that needs to be obtained includes:

- Originating passenger arrival distribution to the terminal,
- Passenger walk speed and group size distribution,
- The distribution of number of well-wishers and number of meeters/greeters,
- The distribution of number of checked and carry-on bags, and
- Originating passengers' first point of contact area and distribution.

The typical airport terminal processing methods data that needs to be obtained includes:

- The distribution of ticket processing time at curbside/ticket/gate check-in counters,
- The distribution of security check processing time,
- The specifications of the corridors and holdroom areas,

- The specifications of the Federal Inspection Station (FIS) area, including different processing times, and
- Inbound baggage processing.

TRACS (TransSolutions' proprietary terminal, roadway, and curbside simulation tool) was implemented to analyze terminal design with respect to passenger and baggage flow. TRACS was developed by TransSolutions using ARENA simulation software. Arena is a general purpose discrete event simulation modeling language supported by Rockwell Software. For more information, refer to www.rockwellsoftware.com. Kelton et al. (1998) described the ARENA tool and basic simulation methodology. Its modular components can account for terminal roadways, ticketing, security checkpoints, corridors, holdroom areas, gates, FIS facility, and baggage claim hall. TRACS is used to determine the design alternative that achieves the desired service levels. TRACS helps determine bottlenecks, improve processing rules, and converge to an optimum design specification through several "what-if" scenarios. Model development with TRACS consists of separate Airport Modeling Templates, which are collection of pre-assembled simulation logic modules of related operations. Each module represents a processing station, terminal area, or piece of equipment in the airport. A module is comprised of the simulation modeling code and animation necessary to develop a working computer simulation of a part of an airport. Airport Modeling Templates have been used and tested by different airport terminal projects throughout the past 10 years. They are robust and less likely to have software bugs than a simulation model that is created from scratch. The use of templates contributes to model development.

3 CASE STUDY

JFK is one of the busiest airports in the world with nine passenger terminals each with its own ticketing, baggage claim, and ground transportation facilities. DL is building a new state-of-the-art facility at JFK, a strategic airport in DL's network. The two new terminals, to be constructed at the site of Terminal 2/3 (T2/3) and Terminal 4 West (T4W), are scheduled to open in year 2010.

The new terminals will accommodate DL's future flight operations at JFK. Plans for the new terminals include:

- More than two million square feet of passenger, baggage, and concession space,
- Two main terminals connected by a bridge,
- A total of 57 gates and six hardstands, and
- Airline product specific operation areas to promote airline product distinction.

DL, in conjunction with their code-share partners, currently serve approximately five million annual passengers through their facilities at JFK. Approximately 45% of these are originating or terminating passengers with the remaining 55% being connecting passengers between domestic and international flights. DL subsequently increased their projected operations significantly with a total requirement of 45 jet contact gates and 12 regional jet contact gates.

DL retained TransSolutions to evaluate the new design's ability to accommodate the projected passenger demand such that DL's performance objectives were achieved. DL tasked TransSolutions with analyzing passenger and baggage flow in the proposed terminals. The evaluation included all originating, terminating, and transfer passenger flows, inbound baggage, curbside processing, ticketing, security checkpoint activities, gates and FIS facility activities. A large-scale discrete event simulation model was used to identify system bottlenecks. The objective of the simulation modeling exercise was to evaluate the service provided to passengers by the proposed terminal concept design. The service provided was measured with respect to several criteria. In this paper, we focus on the time spent as well as travel distance in the terminal by transfer passengers. These statistics were compared with the service levels agreed upon by DL. Recommendations were made that suggested design modifications to improve passenger service levels.

3.1 Data Collection/Data Analysis/ Assumptions Development

Two important pieces of data were supplied by the client, the planning day flight schedule for the year 2010 and the concept layout for the new terminals. Other data was gathered from interviews, information supplied by DL, and previous TransSolutions' studies at similar airports.

Following the data collection and analyses, we prepared an assumptions document presenting the data (summary of statistics and distributions), the description of the system to be modeled, the objectives and any assumptions that were used to create the simulation model as well as performance criteria to be used to evaluate the terminals. This document was reviewed and approved by DL and other project stakeholders including the architectural team, engineering team, and program management team.

3.2 Simulation Model

We have developed a single large-scale simulation model for the passenger and baggage flow activities. Terminal T2/3 mainly serves domestic and regional jet operations whereas Terminal T4W is dedicated to international operations.

The passengers at JFK can be categorized as follows. Refer to Figure 1 for detailed flow charts by passenger types.

- Domestic passengers traveling within the U.S.
  - Domestic originating passengers fly to a domestic airport from JFK.
  - Domestic terminating passengers fly from a domestic airport to JFK.
  - Domestic-to-domestic (D-to-D) transfer passengers fly from a domestic airport to another domestic airport via JFK.
- International passengers traveling to and from an international airport.
  - International originating passengers fly to an international airport from JFK.
  - International terminating passengers fly from an international airport to JFK.
  - Domestic-to-international (D-to-I) transfer passengers fly from a domestic airport to an international airport via JFK.
  - International-to-domestic (I-to-D) transfer passengers fly from an international airport to a domestic airport via JFK.
  - International-to-international (I-to-I) transfer passengers fly from an international airport to another international airport via JFK.

All international passengers go through the FIS facility located at the arrivals level of T4W in order to enter the U.S. Arriving passengers enter the T4W terminal from the arrivals level concourse through a modular structure that organizes boarding, de-boarding, and vertical circulation for each gate position. They walk through the sterile corridor (for passengers who have not yet cleared FIS). The sterile corridor takes the passengers directly to the Immigration and Naturalization Service (INS) inspection area. At INS, passengers go through passport control. A single, continuous band of 70 agent booths lines the INS hall beyond a queue zone. After clearing immigration, transfer and terminating passengers are separated and routed to separate, dedicated baggage claim halls. Once bags are claimed, all passengers must be processed through primary customs at a United States Customs Service (USCS) checkpoint, and also go through United States Department of Agriculture (USDA) X-ray screening. Passengers then proceed to the greeters lounge and exit the terminal if they are terminating passengers or proceed to the baggage recheck facility if they are transfer passengers. After recheck, transfer passengers go through security and proceed to their departure gate.

The final simulation model included:

- Domestic and international passenger processing from arrival at the curbside roadway, transiting to the terminal entrance from the curbside, processing through the ticket counter, processing through security, travel through concourses to the departure gate, and waiting/processing at the departure gate;
- Domestic terminating passenger processing from arrival at the jet bridge, traveling through corridors to the baggage claim or terminal exit, processing at the baggage claim, and traveling to the terminal exit;
- International terminating passenger processing from arrival at the jet bridge, traveling to enter the FIS facility, going through INS, baggage claim, USCS/USDA, and traveling to the terminal exit;
- Domestic transfer passenger processing from arrival at the jet bridge, traveling through corridors to the next destination gate;
- International transfer passenger processing from arrival at the jet bridge, traveling to enter the connecting FIS facility, going through INS, baggage claim, USCS/USDA, and traveling to the boarding gate area of the next flight; and
- Inbound baggage handling operations.

3.3 Results

The strength of simulation lies in the ability to easily compare alternative scenarios. During the initial period of the feasibility study, four alternative designs were developed. The design team chose one alternative design as the final concept design. To evaluate the alternative designs against each other, the design team developed an evaluation matrix. This matrix contains the criteria with which the alternative designs were evaluated. TransSolutions evaluated the alternative designs based on the following criteria:

- Passenger level of service,
- Minimum connect time,
- Passenger walking distance,
- Baggage handling, and
- Required DL staffing.

We have used a “consumer report” style grade assignment and ranked candidate concept designs. Multiple disciplines including architects, structural, electrical, mechanical and industrial engineers, airline customer representatives, and budget and financial consultants were all gathered in one room for a day long session to objectively and independently grade each design with respect to several criteria. One difficult task remaining was to assign weights to determine the winning design. The design team agreed that level of service, connect times, and cost were among the most important criteria, thus given higher weights. Based on the weighted grades, the design team selected the preferred alternative.

In the following sections, we will focus on the minimum connect time and the passenger walking distance measures for the preferred alternative.

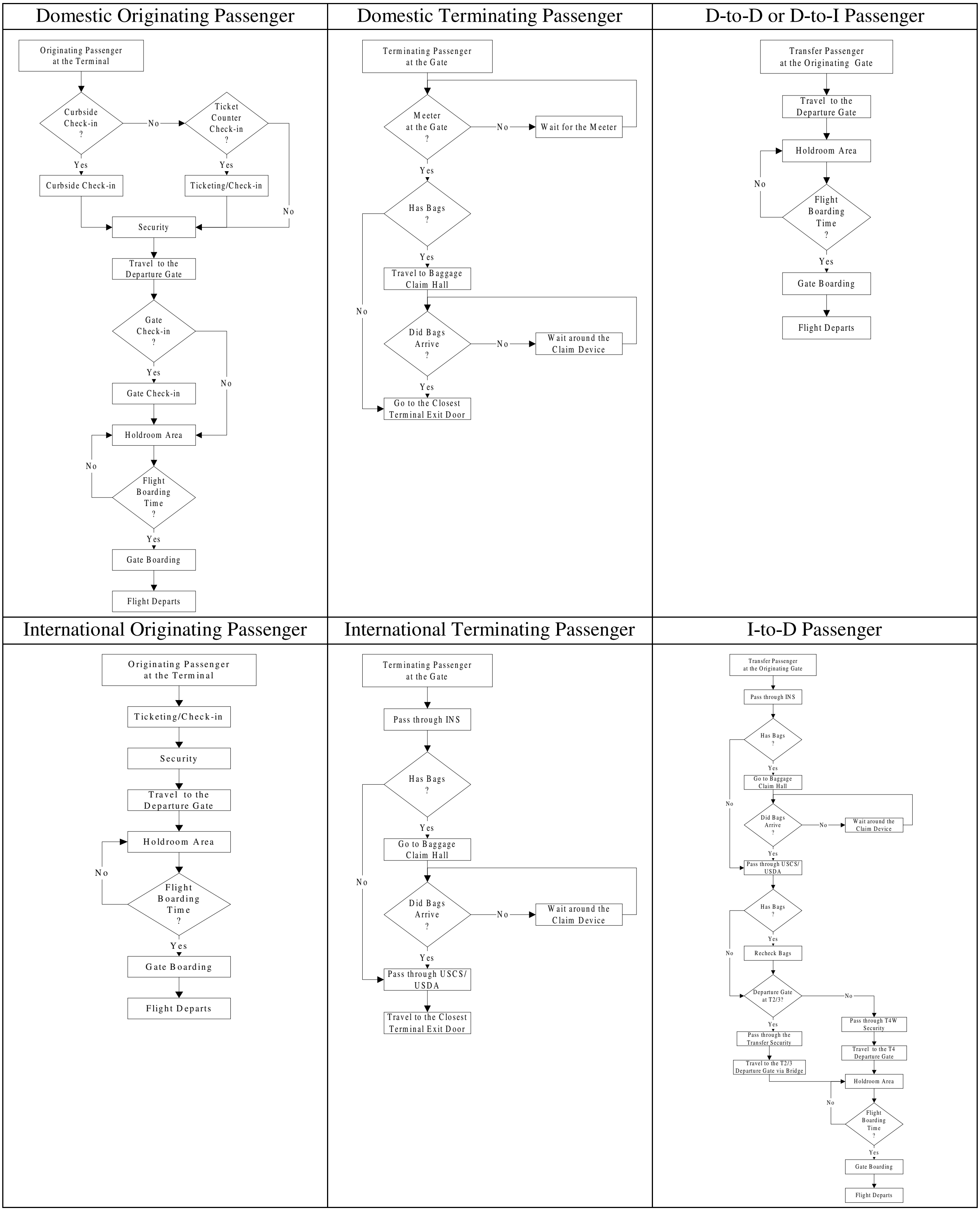

Figure 1: Passenger Processing Flowcharts

3.3.1 Passenger Flow Times

Throughout the simulation experiments, each passenger was tracked and time-stamped at various points within the facility as they progress through the terminal. The model is run as a terminating system where each replication covers the entire day. The model starts empty and idle every day. The model is replicated five times to account for the stochastic nature of the queuing systems. Statistics reported for the averages, maximum, minimum, and percentiles pertain to all replications. Flow time through the terminal is a critical performance criteria and defined separately for each passenger type.

- For both domestic and international originating passengers, the flow time is defined as the time elapsed from their terminal entrance until they reach their departure gate.
- For both domestic and international terminating passengers, the flow time is measured from the flight arrival time until the time passengers exit the terminal.
- For transit passengers, the flow time includes the time from the aircraft arrival time until they reach their boarding gate of the next flight.

shows the time spent by passenger type in the terminal. Statistics for D-to-D and D-to-I passengers were collected together because both go through exactly the same processes until they reach the boarding gate of their next flight. All flow time statistics shown assume that the resources are staffed as they are needed based on the program requirements submitted by DL. If the functional processing areas are not staffed as required by the program, the overall flow times will increase significantly. Note that these statistics take into account the variations in the passenger walking speed, the congestion in the concourses, queues in front of the processors, aircraft deboarding rate, baggage unloading time, and the baggage wait times around the claim devices. All these factors and their interdependencies determine the flow times in the terminals.

Figure 2 shows the distribution of time spent to reach the boarding gate of the next flight. D-to-D and D-to-I passengers spend less time in the terminal than I-to-D passengers. 97% of the I-to-D passengers go to their next boarding gate in less than 45 minutes.

Figure 3 depicts the cumulative flow times for I-to-D passengers who do not go through secondary customs and/or agriculture processing. On the average, passengers reach their departure gate in 31.0 minutes. 95% of these passengers are able to reach their gate in less than 43.0 minutes.

Table 1: Passenger Flow Times in the Terminal (in min.)

Passenger Type	Min.	Avg.	95th Perc.*	Max.
Domestic Originating	2.0	9.6	19.8	43.3
International Originating	5.9	17.0	26.0	49.8
Domestic Terminating	3.2	13.8	26.3	75.0
International Terminating	7.0	22.7	36.9	78.3
D-to-D D-to-I	1.1	15.4	24.1	51.5
I-to-D	12.5	31.3	42.6	78.9

**95% of passengers spend this time or less in the terminal.*

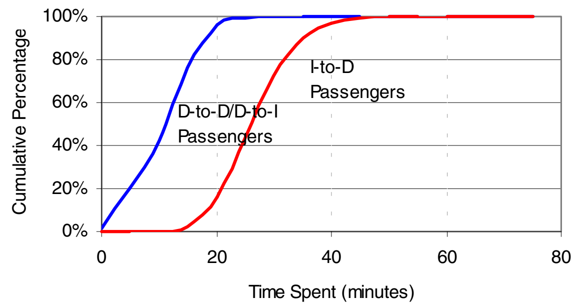

Figure 2: Time Spent to Reach the Connecting Gate

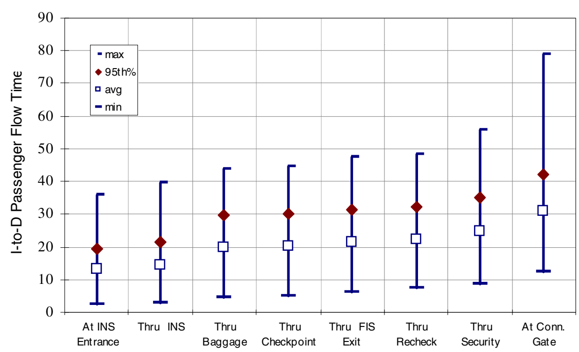

Figure 3: I-to-D Passenger Flow Times (in minutes)

The following figure shows the breakdown of the time I-to-D passengers spent in the terminal. Transfer passengers spent most of their time traveling (more than 60% of their time), and except for baggage claim, all processes account for less than 10% of their time, individually. This suggests that future terminal design improvement efforts should concentrate on travel aid (moving walkways, carts, etc.) and improving baggage claim areas.

3.3.2 Travel Distances

Aircraft gating has a significant impact on the overall travel distances. The travel distance for transfer passen-

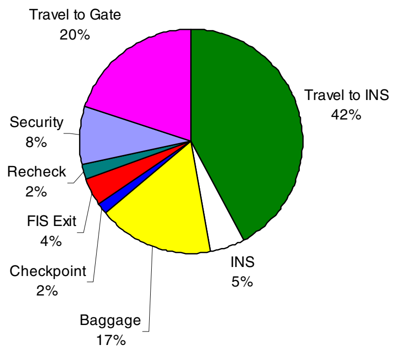

Figure 4: I-to-D Passenger Time Allocation

gers is the distance between the arrival gate and the boarding gate of the next flight. Note that the travel distance for I-to-D passengers includes the distance traveled in the FIS facility. As seen from Figure 5, 5% of I-to-D passengers traveled over 5,000 feet, which is quite a significant distance, suggesting one more time that the use of moving walkways in the terminal design is essential.

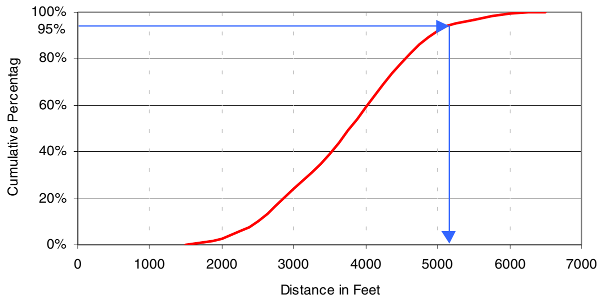

Figure 5: Travel Distances for I-to-D Passengers

4 CONCLUSIONS

With most major airlines operating under the hub-and-spoke system and pairing up with other airlines to offer code share flights, the number of transfer passengers has increased dramatically since the early 1980s. This increase created the need to determine the required minimum connect time between the two consecutive flights in a passenger itinerary for a specific airport. The huge costs associated with a passenger missing a flight motivated the airlines and the airports to work with TransSolutions to evaluate minimum connect times associated with terminal designs.

This paper presents our methodology in using simulation as a design tool for airport terminals. This large-scale project involved many different professional disciplines and simulation proved to be an excellent modeling tool that not only demonstrated and quantified design performance, but also acted as catalyst to bring the whole team together in understanding different components and their interdependencies.

Animation also played a significant role in presenting the design to the upper management in Delta and the New York and New Jersey Port Authority.

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