SIMULATION-AIDED AIRPORT TERMINAL DESIGN

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Abstract—*This paper presents the application of simulation techniques to the design of a new passenger terminal at Curaçao International Airport. The purpose of the simulation was to confirm that the design would meet or exceed International Air Transport Association (IATA) level of service C (LOS C) planning standards during peak activity periods of the design day. The simulation model is a dynamic, object-oriented passenger movement analysis tool. The model is driven by a realistic flight schedule developed for a 24-hour design day, thereby providing passenger volumes and flows that reflect the arrival and departure of aircraft and passengers over the course of an entire day.*

Keywords—*airport terminal, design, level of service, passengers, planning, simulation*

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INTRODUCTION

The new terminal at Curaçao International Airport (see **Figure 1**) began operating in July 2006. When it opened, the terminal was capable of handling 1.6 million passengers annually, although that traffic level is not expected to occur before July 2011. Its ultimate capacity will be 2.5 million passengers per year. The airport is a terminal for Caribbean Basin traffic serving mainly European (primarily Dutch) and US tourists (via Miami), and a small business segment. There is also a very small number of transfer passengers to and from other islands in the Netherlands Antilles region, including Aruba, Bonaire, and St. Maarten.

When the new terminal was being designed, 18 airlines were expected to serve the airport, including three U.S.-based companies, American, Continental, and Delta. One airline, Dutch Caribbean Express, was expected to carry almost half of all passengers and connect Curaçao to the main Caribbean islands of Jamaica, Haiti, Santo Domingo, Trinidad and Tobago, and the other islands in the Netherlands Antilles region, including Aruba, Bonaire, and St. Maarten; and to cities in nearby Venezuela, including Caracas, Valencia, and Maracaibo. The airline would also offer long-range flights to Miami and Amsterdam. Other airlines would serve several South American countries, including Venezuela, Colombia, Surinam, and Peru, and Central American countries, including Costa Rica. Flights to Cuba and Puerto Rico would also be available from Curaçao. The projected activity meant that Curaçao International Airport was poised to become a flexible and convenient hub for the Caribbean Basin.

Figure 1. Architectural Rendering of the New Curaçao International Airport Terminal and Concourses at Opening

ABBREVIATIONS, ACRONYMS, AND TERMS

AOCI	Airports Operations Council International
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
CAD	computer-aided design
CADD	computer-aided design and drafting
FAA	Federal Aviation Administration
IATA	International Air Transport Association
IEEE	Institute of Electrical and Electronics Engineers
LOS	level of service
LOS C	[IATA] level of service C [standards]
SCS	Society for Modeling and Simulation International
TD&I	Transportation and Development Institute [of ASCE]

> *The most challenging conditions in the terminal occur when two B-747s arrive at the same time during a peak hour.*

Equipment used to serve this market varies from long-range, E-size aircraft with 400 seats, such as the B-747, to small, twin turbo prop aircraft with 48 seats, such as the de Havilland Dash 8. Each day, three B-747 flights from Europe will arrive in Curaçao from London, Madrid, and Amsterdam. To serve these flights, the apron was designed with 12 positions, 5 of which have access to the terminal via passenger loading bridges. There are three positions for B-747s, three for B-767s, and six for Dash 8s.

The airport has a curfew at night from approximately 11:00 p.m. to 6:00 a.m. When flights resume, activity builds to a midday peak, when nine aircraft arrive during one hour, representing 15 percent of daily aircraft arrivals. A second peak is reached at a later hour, when nine aircraft depart. During these two hours, passenger peaks are also reached, with 920 passenger arrivals and 940 departures (more than 18 percent of daily passengers).

The most challenging conditions in the terminal occur during a peak hour when two B-747s arrive at the same time. The terminal is designed with sufficient facilities and public space so that the level of service (LOS) during this peak will not drop below IATA LOS C standards.

Because of the high level of concentrated activity at such a compact airport, it was more difficult to apply the planning methodologies advocated by IATA and the FAA. Therefore, it was decided that, in addition to the IATA and FAA methodologies, a passenger simulation model would be used for the design. The simulation model makes it possible to quantify the LOS in each area of the terminal and for each type of airport patron, given a specific terminal size and layout and a specific scenario of arriving and departing flights during a 24-hour day (the design day).

PASSENGER SIMULATION MODEL—TERMSIM

TERMSIM, Bechtel's proprietary simulation package, enables the airport planner to quantify the level of service experienced by passengers going through a specific terminal layout, for a traffic level based on a forecasted design day flight schedule.

The simulation model is driven by the design day flight schedule, in which each flight has a time of arrival or departure, consists of a specific aircraft type, is assigned to a specific gate or remote stand, and belongs to a specific airline with a unique flight number.

In addition, the number of originating or terminating passengers and the number of transferring passengers in each flight are based on projected load factors. These passengers are further divided into first, business, and economy classes.

For each departing flight, profiles of originating passengers are generated in the model at a time determined by their scheduled departure time and an earliness-of-arrival distribution. Once created by this process, each originating passenger has the following attributes:

- Travel class (first, business, or economy)
- Time and location of arrival at the airport
- Ground transportation mode used
- Airline and flight number
- Departure boarding lounge

In addition, each originating passenger is assigned the following attributes:

- Number of people travelling together in a party (party size distribution)
- Number of checked bags per passenger based on a bag distribution range, as well as a probability distribution that a percentage of these bags are oversized or require special handling (e.g., animals)

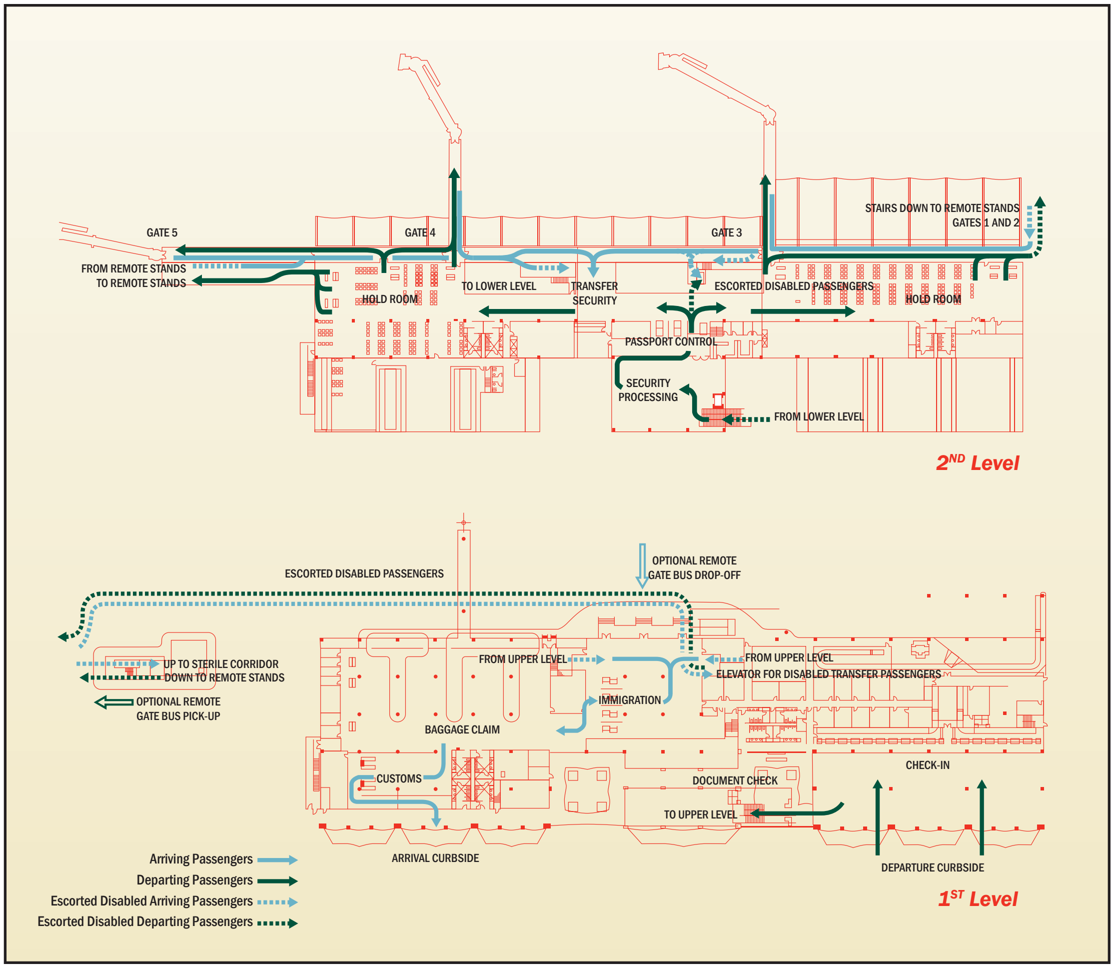


Figure 2. Curaçao Terminal Airport Passenger Flows

> *The Curaçao Airport terminal model simulates real-time behaviors. For example, while moving through the terminal, passengers have the option of walking or using a moving walkway.*

- Number of carry-on bags per passenger sampled from a distribution range
- Number of well-wishers per party sampled from a well-wisher distribution range
- Special needs passenger assumptions to account for wheelchairs or electric carts

A similar process is used to generate terminating and transferring passenger profiles in arriving flights at their specific gate or hardstand, with appropriate attributes assigned as the passengers exit the aircraft and move into the terminal or in a bus.

The passengers thus generated move within the terminal and concourses from one area to another according to their attributes. Each area or processing station has a location in the model specified by an x, y, or z coordinate that is tied to a scaled CADD drawing of the terminal, such as the one in **Figure 2**. The distance between two areas is calculated as the most direct distance along a travel route. Or, when a straight line between two areas is not physically possible, intermediate points are defined through which the passengers must pass.

Walking time between areas is computed by giving each party a walking speed, sampled from a distribution between a minimum and a maximum. Two such speed distributions are used: one for passengers with special needs and one for all other passengers. These speeds are reduced when the occupancy of the area that the passengers traverse rises above a given threshold (crowding effect). Randomization of walking speeds is used to reflect the reality of people moving in a terminal.

The model simulates real-time behaviors. For example, while moving through the terminal, passengers have the option of walking, using a moving walkway, or boarding the automated people-mover. When changing levels, they can use escalators, elevators, or stairs. On the escalators and moving walkways, some passengers will stand while some will walk, adding their speed to that of the escalator or walkway.

When passengers arrive at a processing area, they join a queue. Queues can be universal (a single queue serving several identical processes or checkpoints) or individual (one queue per process or checkpoint). When passengers reach the head of the queue, they are processed. The processing time is a value sampled from a distribution range specific to each facility and passenger attribute.

As passengers move through successive processing checkpoints or areas in the terminal and concourse, their movement is followed by the model and statistics are generated. The occupancy of each area (circulation or queuing) is tracked during the 24-hour simulation period. At each processing point the flow of passengers and queue length is tracked during the day and these data points are, in turn, used to assess the different LOS metrics.

The simulation model collects all of the output variables on a minute-by-minute basis.

The model collects all of these output variables on a minute-by-minute basis. This enables the planners and architects to design facilities, public spaces, and corridor widths for the peak traffic activity of the design day.

INPUT ASSUMPTIONS

Input assumptions fall into four categories:

- **Description of terminal spaces and processing facilities.** This is summarized in the CAD drawings of each floor plan of the terminal building and of each concourse. On each drawing, the flow paths of originating, terminating, and transferring passengers are shown, as well as the paths of the electric carts.
- **Flowchart of passenger circulation and processing.** For each category of passengers (originating, terminating, and transferring), a flowchart describes all the facilities the passengers have to visit, and the order in which the facilities are traversed, from the time passengers arrive at the airport until they leave the airport.
- **Functional description of each processing facility and subfacility.** For each category of passenger, a detailed table summarizes the facility parameters such as the percent of passengers using it, together with the processing time distribution (maximum, minimum, and average). Some facilities have no associated processing time, but passengers wait a specific length of time (e.g., well-wisher leaving point in departure hall) or wait for a specific event (e.g., boarding call in the departure lounges).
- **Minimum acceptable LOS in each facility and subfacility.** In addition to the IATA levels of service, which are based on areas available per passenger, a maximum dwell time not to be exceeded is specified (queuing time plus processing time). Likewise, a 90 percentile dwell time is also specified. This means that 90 percent of the passengers processed at that facility should have a dwell time shorter or at most equal to that criterion.

SIMULATION OUTPUTS

The results of the simulation are summarized in five categories:

- **Determination of facilities requirements.** When the simulation run is progressing, the model automatically adds facilities to ensure that the desired LOS is not exceeded when the demand for this facility keeps growing. For instance, at the economy check-in, when the waiting time for 90 percent of the users exceeds 10 minutes, a new counter is opened.
- **Performance of each processing station.** The number of passengers processed during the design day is summarized in a comprehensive table for each processing station, together with the percentage of passengers that did not have to wait in a queue, the mean wait time and maximum wait time for all passengers, as well as the maximum queue length.
- **Queuing areas.** Groups of processing stations are generally fed from a single queuing space (universal queue). For instance, multiple economy check-in counters are fed from such a single, universal queue. The LOS in the queuing area is determined by the number of passengers and the size of the queuing area, using the IATA criteria. For each queuing area there is a graph showing the number of passengers in the queue every 10 minutes, together with lines showing the boundaries between LOS as shown in **Figure 3**.
- **Clearance times.** At the end of the simulation, each passenger from each category "remembers" the time spent in the airport, between the time of arrival or departure at a gate and the time of entrance or exit from a ground access mode. These clearance times are then ranked from the shortest to the longest and displayed in separate histograms for terminating passengers, originating passengers, and transferring passengers.
- **Space occupancy.** For boarding gate lounges and public lobbies where people are waiting in a given space, an occupancy graph is

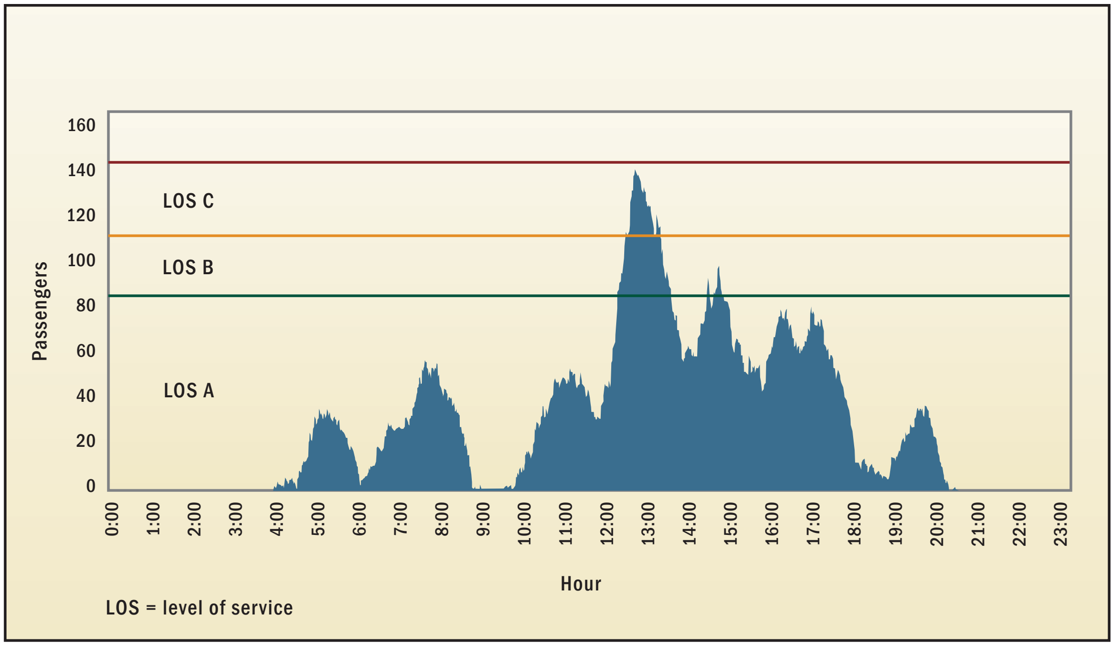


Figure 3. Check-In Counters Queuing Area Passenger Density Distribution in 2031

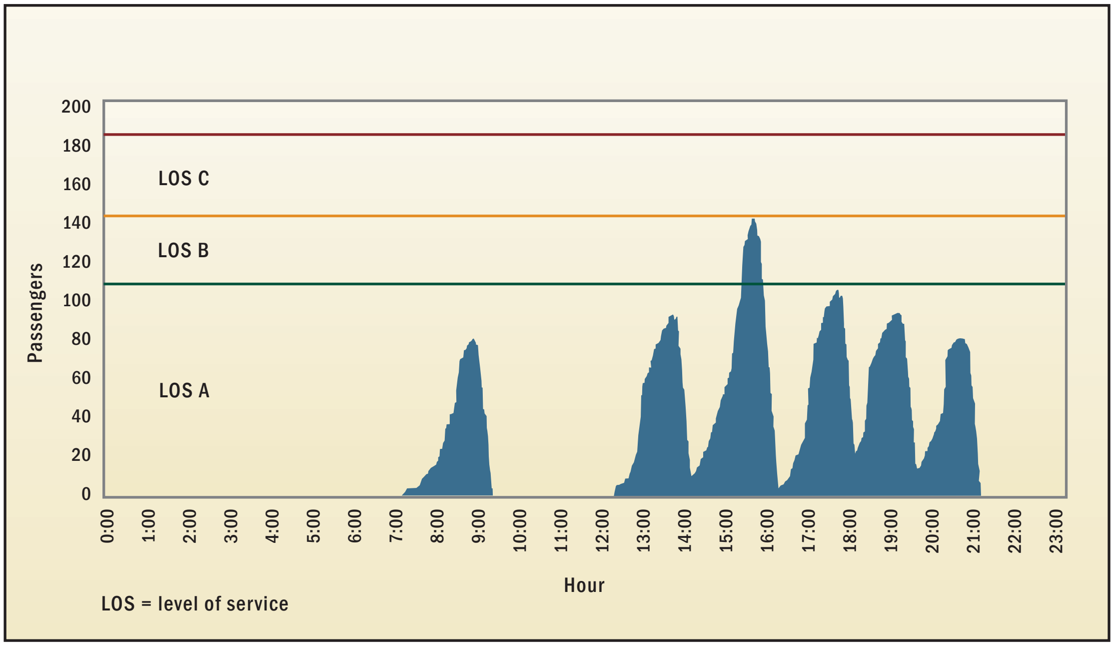


Figure 4. Boarding Area (Boarding Lounge Gate C001) IATA LOS Distribution in 2031

given, as well as a graph of the corresponding LOS, based on IATA criteria, as shown in **Figure 4**. For corridors, where people are walking, similar graphs are given, based on people per minute walking past a cross-section. The LOS is calculated by cordoning off a section of the corridor with virtual doors and counting how many people are in this section every 10 minutes. The number of people in that section is found by adding one every time a person passes the virtual entry door and subtracting one whenever a person passes the virtual exit door.

CONCLUSIONS

Curaçao is a small, compact airport in a very dynamic environment. In the contract, one of the performance specifications items was to demonstrate that even during peak hours of the ultimate forecast, the LOS should be at IATA LOS C standards or higher. TERMSIM, Bechtel's proprietary simulation package, made it possible to quickly investigate the performance of different terminal layouts and translate them into the design changes necessary to accommodate the traffic projections at desired design standards. Because TERMSIM can be used at different levels of detail, its use is practical and effective, even for small airports like Curaçao. ■

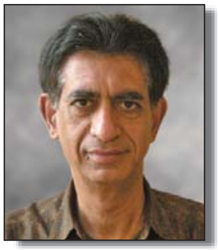
BIOGRAPHIES

Michel A. Thomet is the manager of facility planning and simulation for the Aviation Services Group in San Francisco, California. He has been involved in the master planning of transportation infrastructure megaprojects around the world, including airports, rail systems, transit systems, ports, mines, and industrial cities. On these projects, Dr. Thomet has been responsible for simulation studies (capacity, level of service), traffic forecast studies, economic feasibility studies, and noise and air quality impact studies. He currently supports the New Doha International Airport project in Qatar.

Previously, Dr. Thomet was the planning director at Suiselectra in Basel, Switzerland, where he coordinated a team of experts in various fields related to transportation, and traveled widely in Europe and North America to gain first-hand knowledge of state-of-the-art urban transportation systems. Earlier, as a senior electric engineer at the Westinghouse research and development laboratories in Pittsburgh, Pennsylvania, he conducted research on solid state power conversion systems.

Dr. Thomet is a member of the Institute of Electric and Electronics Engineers (IEEE), Society for Computer Simulation (SCS), and the Transportation & Development Institute (T&DI) of the American Society of Civil Engineers (ASCE). As a member of the executive committee of the Vehicular Technology Society of IEEE, he has been involved in preparing and supporting the annual American Society of Mechanical Engineers (ASME)/IEEE Joint Railroad Conference. Dr. Thomet has authored and published 12 technical papers (4 on electrical engineering and 8 on transportation), several of which have been presented at the Winter Simulation Conference (WSC) and at conferences sponsored by the IEEE, ASME, and Airports Operations Council International (AOCI).

Dr. Thomet received an MBA in Management and Economics from the University of California, Berkeley; has a PhD in Systems Engineering and an MS in Electrical Engineering, both from Carnegie Mellon University, Pittsburgh, Pennsylvania; and received a Diploma in Electrical Engineering from the Federal Institute of Technology, Zurich, Switzerland.



Farzam Mostoufi is a senior planning and simulation specialist with Bechtel Civil, with 20 years of experience at Bechtel in the planning and design of transportation and material handling facilities, including international airport terminals, railroads, transit systems, bulk and container ports, and mining and metals production complexes. He is highly experienced in conducting technical simulation studies and economic analysis, and in the design, development, and use of specialized transportation and logistics models.

Farzam has developed economic models and participated in feasibility studies to test the impact of projected operations and designed facilities on revenues, capital expenditures, and maintenance costs. He is currently supporting the New Doha International Airport project in Qatar, being designed to meet Qatar's aviation needs for decades to come. When the airport opens in 2011, as many as 8,000 passengers will be able to use the 590,000+ m^2 passenger terminal complex in a single hour, and the 4,850 m eastern runway will be among the longest commercial runways in the world, allowing for unrestricted operations by Airbus A380 aircraft even under extreme meteorological conditions.

Farzam received an MBA in Finance from Golden Gate University, San Francisco, California; has a BS in Economics and Insurance from Tehran College, Tehran, Iran; and has completed course requirements in the Doctor of Business Administration (DBA) degree program at Golden Gate University. As a lecturer at Golden Gate University, he taught graduate and undergraduate level courses in computer modeling, simulation, and database systems. Farzam also holds a Certificate in Airport Systems Planning from Massachusetts Institute of Technology, Cambridge, Massachusetts.