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APPLICATION OF SIMULATION MODELS IN AIRPORT FACILITY DESIGN

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ABSTRACT

Lester B. Pearson – Toronto International Airport is undertaking a $4.4B development program comprising a new 390,000 sq. m. terminal building (replacing two aging terminals), three new runways, cargo facilities, a central utilities plant, and an expanded road system and parking facilities. This activity is proceeding while the airport continues to operate and while requirements evolve in response to rapid changes in the airline industry. The airport has used and continues to use airport simulation models to assist in the development of program requirements and to validate design. For example, computer models have been used to generate population estimates to determine impacts on HVAC requirements and to simulate queuing at check-in counters and pre-board security screening points. This paper will discuss calibration methods and the application of simulation results in the design process. Finally, the impact of the changed environment since September 11, 2001 on airport design will be discussed.

1 INTRODUCTION

Lester B. Pearson – Toronto International Airport (herein referred to as Pearson) handles about half of Canada's air traffic. About 29.0 million passengers pass through it annually; 1,200 aircraft arrive or depart every day. Current facilities include three terminals. Terminal 1 was built in 1964 and was not designed to handle today's newer and larger aircraft. Terminal 2 was built in the 1970s as a cargo terminal and 'temporarily' converted to a passenger terminal. After several additions and renovations, the terminal is nearing the end of its design life. Terminal 3 is about 10 years old, and was designed for current and future market conditions. Projections of air travel in and out of Toronto show that the number of passengers is expected to reach 50 million by 2020. Because the airport is near capacity now, with major renovations required soon, serious evaluation was required to develop a long term plan for the airport.

Pearson was a federally controlled operation from its opening in 1939 until 1996, when the management, operation and maintenance of the airport was privatized and contracted to the Greater Toronto Airports Authority (GTAA), a nonprofit, publicly held corporation.

Upon assumption of its new responsibilities, the GTAA developed a new Master Plan to meet airport long term needs. Based on this plan, the GTAA is in the midst of a major expansion program intended to increase the capacity of airside and groundside systems to their ultimate potential. As part of this effort, the Terminal Development Program (TDP) will ultimately replace the three original terminals with a single, unified terminal building, beginning with the oldest structure (Terminal 1) and continuing with the phased closure and replacement of Terminals 2 and 3. In order to assess the detailed plans and design for the staging and construction of the TDP, the GTAA Planning Department makes extensive use of a passenger terminal simulation program known as ARCTERM.

ARCTERM generates files tracking the movement of individual passengers and visitors through the various processors in a simulated terminal building, using information derived from surveys (processing times, passenger and visitor lead times) and a detailed flight schedule as input. Once result files have been created, ARCTERM provides an animated playback of passenger and visitor movement against a CAD-based background drawing, allowing visual identification of areas where congestion or conflicting flows may occur. ARCTERM also generates reports that can pinpoint problems such as excessive queue lengths, poor spatial Level of Service (LOS) (overcrowding) in particular areas, and long walking times and distances. The GTAA uses information derived from ARCTERM simulations to assess options for modifications to existing terminals and for design of new facilities.

2 ARCTERM HISTORY AND CHARACTERISTICS

ARCTERM is a stochastic computer modeling tool specifically designed for simulation of passenger processing in airport terminal buildings. It was developed by Aviation Research Corporation, Inc. of Port Roberts, Washington.

ARCTERM uses CAD drawings as guides for placement of processors and as backdrops for animated display of results, allowing internal tabulation of passenger walking distances and times and of passenger density within any user-selected area. The primary input for an ARCTERM simulation run is a flight schedule, specifying airline, flight number, aircraft type, gate, arrival time and/or departure time, and passenger load(s). The program generates passengers, visitors, and deplaning bags based on the flight schedule and on user-defined parameters such as lead-time distributions, visitor-to-passenger ratios, bag-to-passenger ratios, passenger walking speeds, etc.

Within a model, each passenger moves from processor to processor based on user-defined empirical distributions (a fixed percentage being assigned to each option for a given passenger type). The time spent by a given passenger at a given processor is again based on a user-specified distribution for that passenger's type. (Examples of passenger type: business; pleasure; Domestic business; transferring Domestic business; etc.)

Once a simulation run has been completed, the model can generate various reports relating to:

- passengers (entry and exit times; queuing, processing, movement, and baggage wait times; time spent in holdrooms; distance traveled);
- processors (processing times; queue lengths; throughput per time interval); and
- space (total terminal occupancy per time interval; occupancy for a user-selected area per time interval).

The animated playback feature provides a graphical display of passenger movements and allows visual identification of areas of congestion, conflicting passenger flows, and excessive queue buildup.

3 APPLICATION OF ARCTERM TO TERMINAL DESIGN AND PLANNING

The following section describes how the GTAA Planning Division has used ARCTERM as a practical decision support tool.

Over time, the traffic assigned to each terminal at Pearson has changed in terms of the specific airlines involved and in terms of the volume of traffic in each flight sector (Domestic, International, and Transborder (Canada-U.S.). This has led to imbalances in the processing capacities of facilities (e.g., insufficient security screening capacity to process demand generated by expanded check-in areas). ARCTERM has been used on several occasions to assess the effect of adding different numbers of security screening stations on queue accumulations and passenger waiting times, and thus to determine the optimum number of security screening stations to be added.

More recently, ARCTERM has been applied to the problem of assessing the impact of proposed changes to security screening procedures. The modeling functionality of ARCTERM has allowed Planning to simulate various configurations that combine existing security screening equipment and processes with new equipment and processes that must be implemented (Explosives Detection Systems (EDS) inspection of carry-on bags). These simulations have allowed Planning to identify the critical elements of the enhanced screening process and thus to estimate the throughput capacity of each security screening station before the new equipment and procedures come online. The combination of single-thread, parallel and optional elements involved in the security screening process would make any such assessment difficult in the absence of a simulation tool such as ARCTERM.

3.1 Evaluation of Conflicting Passenger Flows in Two New Terminal Design Options

The design of the new terminal has undergone a number of changes as negotiations have proceeded between the GTAA, airlines, and government inspection agencies. At one point, the agency responsible for operation of the Customs Primary Inspection Line (PIL) had requested that some consideration be given to physically dividing the PIL area to separate "low-risk" and "higher-risk" passengers. This request resulted in the creation of two conceptual layouts, each featuring two separate entrances to the PIL area and a physical division of the PIL area itself.

Because of the prevailing scheme for allocation of gates to different flight sectors, this would have required streams of passengers en route to departing International flights to cross streams of passengers en route to the entrance to the "low-risk" portion of the PIL. The two layout options varied mainly in the location of the "low-risk" entrance relative to the central axis of the pier (and PIL area).

The GTAA set up the two layouts as separate instances of the ARCTERM model, and executed simulation runs for each. Visual inspection of the animated playback for each option confirmed that there were periods when significant flows of arriving and departing passengers would cross in the area outside the entrances to the PIL area in both cases. However, measurement of the actual number of passengers affected (as the throughput for specific processors in each flow) demonstrated that one option had a significant advantage. A side effect of this exercise was the discovery that the ratio of "low-risk" to "higher-risk” passengers varied considerably by time of day. This would make it impractical to install a fixed physical barrier to separate the “high-risk” and “low-risk” portions of the PIL, since any division of the total space would cause undue congestion on one side or the other during some part of the day. The final result was that the divided-PIL concept itself was essentially discarded.

3.2 Estimation of Maximum Occupancy of an Area to Determine Heating/Ventilation System Requirements

As design of the new terminal has continued, more practical issues have taken on greater significance. The specifications for the Heating, Ventilation and Air Conditioning (HVAC) system to serve the central pier of the new building had to be determined to allow sizing of the associated ducts and mechanical rooms. The required capacity of the HVAC system would be determined by the maximum occupancy of the areas served by it, in combination with other factors such as the effects of sun exposure, the potential for air flow between areas, etc. Gross estimates based on the combined capacities of the largest aircraft that could be accommodated on each of the gates on the central pier suggested one range of system loads; other estimation methods suggested lower ranges, and significantly lower costs.

The GTAA executed an ARCTERM simulation run with the most recent predicted flight schedule and gate assignment scheme available, and then ran the ARCTERM Passenger Density Report for various areas in the central pier. This allowed calculation of somewhat more realistic occupancy profiles, and thus permitted the engineering consultants to determine the requirements for the HVAC system with greater confidence.

3.3 Evaluation of Overall Level of Service in the New Terminal

With the opening of the first phase of the new terminal only a few years away, the GTAA decided that an overall assessment of potential problem areas was needed. Thus, the GTAA undertook a comprehensive Level of Service (LOS) assessment for the new terminal building based on the detailed 2015 Planning Day traffic schedule. The model was updated to reflect the latest design and passenger flow options as closely as possible, and then a simulation run was executed.

Various reports were used to generate information for spatial and dynamic LOS ratings, as follows:

1. To assess spatial LOS in holdrooms, queuing areas, and the arrivals public concourse, the Passenger Density Report was executed for each area in turn, with 15-minute resolution. The resulting data was used to generate profiles of space per person and compared to the acceptable industry Level of Service standards. Figure 1 is an example of a chart showing the spatial level of service for a particular departures holdroom in numeric form, with results weighted by the percentage of the operational day during which the indicated conditions were in effect. Figure 2 shows data for the same departures holdroom categorized by Level of Service letter codes (with “C” being the target 90th percentile Level of Service for the terminal design year of 2015). The spatial Level of Service letter codes, ranging from “A” through “E” (with “F” representing level “E” persisting for longer than 15 minutes) were originally defined in the Transport Canada paper, “A Discussion Paper on Level of Service Definition and Methodology for Calculating Airport Capacity”. These codes are still widely used by Canadian airports as a standardized means of expressing the degree of crowding in a terminal building (air, rail, etc.).
2. To identify any areas where wait times exceeded reasonable limits, the Time in Queues Report was executed for each distinct check-in area, the US

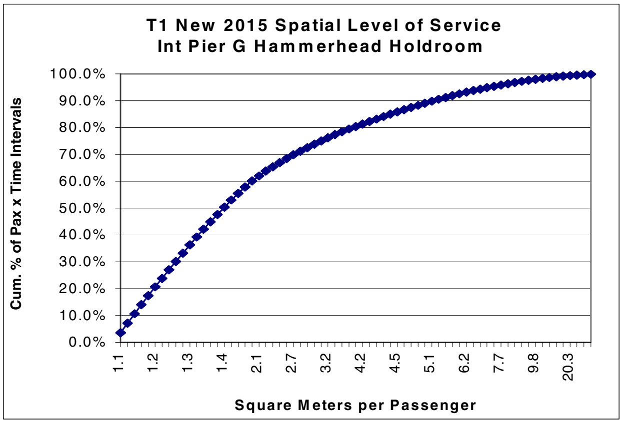

Figure 1: Sample Space per Passenger Chart

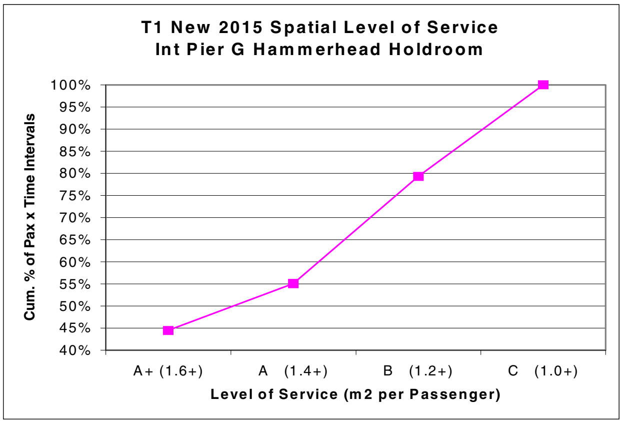

Figure 2: Sample Spatial LOS Distribution Chart

Pre-clearance facilities, the Canadian Inspection Services PIL, and each pre-board security screening area. The resulting data was compared to airline and other standards to identify areas where wait times would be considered unacceptable. Figure 3 shows the cumulative distribution of wait times for passengers accessing the U.S. Departures check-in counters.

3. To determine required lead times for departing passengers, the Activity Breakdown Report and Passenger Log Report was executed for each flight sector, and the resulting data was used to generate profiles and distributions of Curb-to-Holdroom times. These figures were then compared to values suggested by the airlines as targets based on current operations. Raw Movement Times were derived directly from the Activity Breakdown Report. A second Movement Time was then calculated for each passenger assuming that he/she would make use of all moving sidewalks (travelators) along his/her route to increase his/her speed. The two resulting time distributions were then compared to establish upper and lower bounds for walking times. Figure 4 shows the differing cumulative distributions of in-terminal travel times for International originating passengers with and without travelator usage.
4. To determine dwell times for arriving passengers, the Activity Breakdown Report and Passenger Log Report was executed for each flight sector, and the resulting data was used to generate profiles and distributions of Gate-to-Curb times. These figures were compared to values suggested by the airlines and by Canadian inspection agencies. As with Gate-to-Holdroom Times, two sets of Movement Times were used: the raw values from the Activity Breakdown Report, and adjusted values assuming optimum utilization of travelators. Figure 5 shows the differing cumulative distributions of in-terminal travel times for terminating passengers from the U.S. with and without travelator usage.
5. To determine minimum connect times between flight sectors, the Activity Breakdown Report, Passenger Log Report, and Distance Traveled Reports were executed for each arriving flight sector. Data was aggregated by arriving flight/departing flight combinations to permit calculation of time distributions for different combinations of arrival and departure gates. Next, estimates were made of the total distance covered by moving sidewalks for each gate combination. Finally, adjustments were made to the Movement Time and total time to account for utilization of the moving sidewalks, assuming that passengers would walk at their

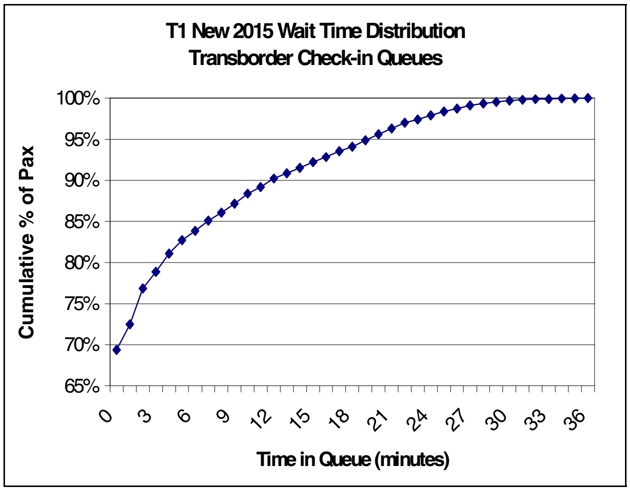

Figure 3: Sample Wait Time Cumulative Distribution Chart

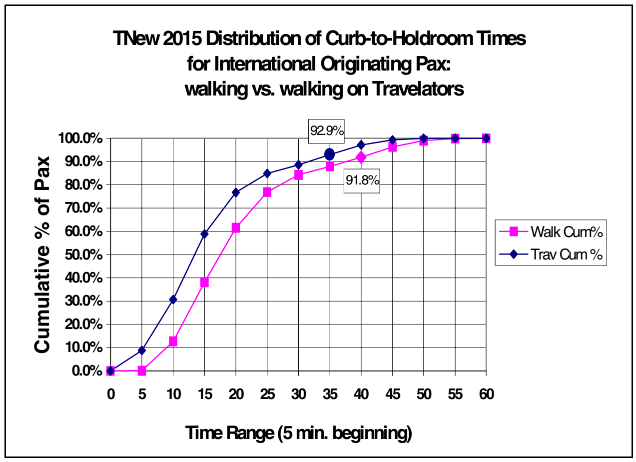

Figure 4: Sample Curb-to-Holdroom Time Distribution Chart

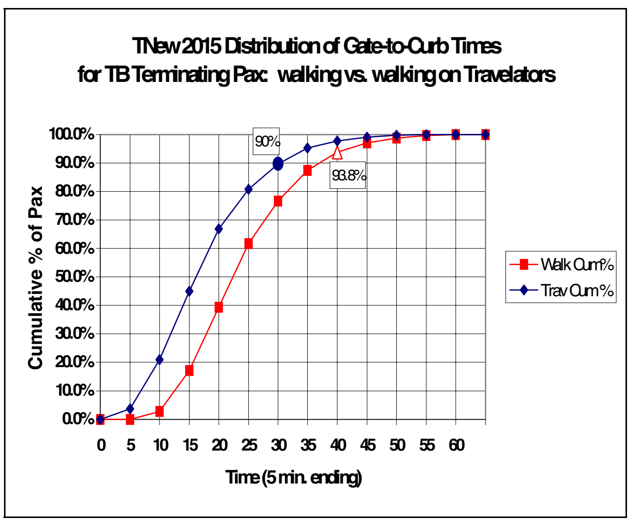

Figure 5: Sample Gate-to-Curb Time Distribution Chart

normal speeds on the moving sidewalk units (thus adding their speed to the speed of the moving sidewalk). The results were compared to values suggested by the airlines. Figure 6 shows the cumulative distribution of connection times between distant Domestic and International gates; Figure 7 illustrates the routes and distances that passengers making these connections would have to travel in-terminal.

Overall, there were only a few areas where the results of the simulation indicated cause for concern. The level of service that would be potentially experienced by passengers at various locations in the building was likely to be very high.

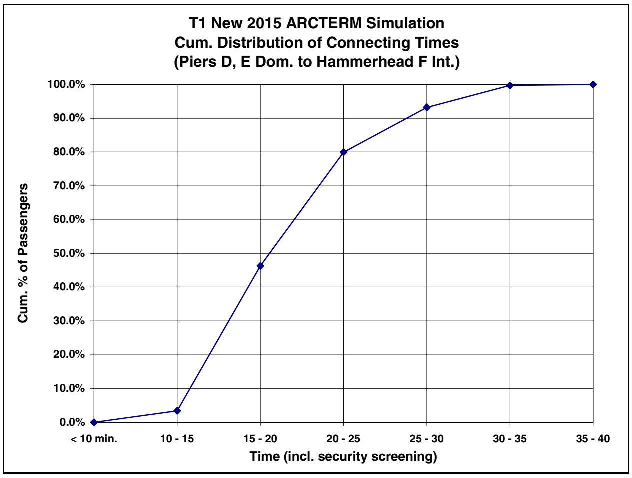

Figure 6: Cumulative Distribution of Domestic to International Connection Times

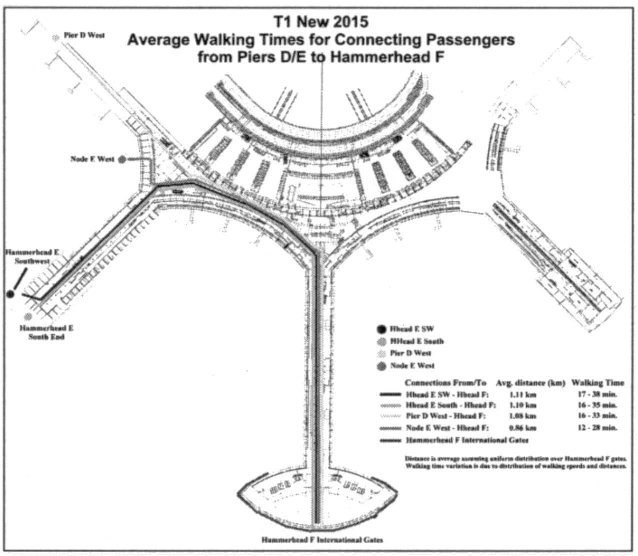

Figure 7: Domestic to International Connection Route Diagram

3.4 Assessment of Terminal Design Post September 11, 2001

The events of September 11, 2001 have led to sweeping changes in the complexity and scope of security measures that must be incorporated into both existing and new passenger terminals. The design of the new terminal building already included provision for installation of checked-bag screening equipment into the outbound baggage sortation systems, but this equipment must be retrofitted in Terminals 2 and 3 to the extent that space permits.

Other areas affected include the “lead time” distributions for departing passengers, and processing rates at check-in, Canadian and U.S. inspection services, and pre-board security screening.

In the period immediately following resumption of commercial flights, departing passengers were advised to arrive at the airport as much as two to three hours earlier than had been the case prior to September 11, 2001. Extremely long queues were observed at check-in and at pre-board security in airports around the world as new procedures were implemented. Subsequent months have seen a gradual reduction in the lead times recommended by airlines and airport operators as procedures have been streamlined and stabilized; however, it is expected that lead times will be permanently affected to some extent due to the introduction of more complex and time-consuming security measures. Thus, pre-September 11 lead time distributions have been shifted back (earlier) by approximately 30 minutes in GTAA ARCTERM simulations for the new terminal.

Check-in processing time has been affected somewhat by more stringent requirements for verification of the identity of each passenger through examination of documents (passports, driver’s licenses, etc.). ARCTERM simulations using new estimates of typical processing times will be used to verify that an adequate number of check-in positions are available.

Pre-board screening of passengers and carry-on items has been enhanced by the introduction of chemical vapor-trace detection equipment and more thorough search procedures. As noted earlier, ARCTERM has been used to analyze the impact of incorporating EDS inspection to the pre-board security screening process. ARCTERM animation allowed a better understanding of the likely impact of the new procedures on the throughput capacity of each screening station. The revised estimates of throughput capacity then allowed reassessment of the number of screening stations needed to handle projected peak demand in the existing terminals and in the new terminal.

4 CONCLUSION

An airport project of the size and complexity of the Toronto International Airport redevelopment requires careful planning and a responsive design process. ARCTERM simulations have provided and will continue to provide the flexibility to test design elements as they evolve in response to the rapidly-changing aviation industry environment.

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AUTHOR BIOGRAPHIES

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