An Optimum Resource Utilization Plan for Airport Passenger Terminal Buildings

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An ideal and practical procedure was developed to optimize resource utilization of airport Passenger Terminal Buildings (PTBs). Each procedure consists of three parts, that is, the PTB operation, an optimization model, and a flow management and control model. In the ideal procedure, it is assumed that a real-time flow management and control technique can be applied on an actual terminal building to dynamically allocate the optimum required resources, obtained from the optimization model, to a highly variable demand. The output of this procedure would be a variable time-resource plan and theoretical optimum operations cost. In the practical procedure, the PTB is simulated using a new object-oriented graphical modelling technique, the SES/workbench. The object and submodel support of this tool allowed rapid development of the simulation model capable of representing a wide variety of PTBs. Statistics from the simulation model are used to develop an optimization model, based on the resource allocation theory, to yield the optimum required resources for each segment of the building at each instant of time. It is also proposed that the results of the optimization model, a variable time-resource plan, can be implemented by application of some site-specific flow management and control strategies. As a result, the procedure will provide a practical variable operational and maintenance cost. How close one can bring the practical cost to the theoretical one depends on the flexibility of the PTB layout and the capability of flow management and control technique.

Capital and operational costs of airport passenger terminal buildings (PTBs) are very extensive. Taking into account the fact that airport PTBs are some of the most expensive public transportation facilities, the goal of public policy should be to ensure that these resources are employed as effectively as possible. A quick review of the existing literature gave the impression that for most of the planning horizon, airport terminals have an oversupply of facilities, for example, space. However, various interest groups are concerned about the negative impacts of insufficient supply during certain time periods, for example, congestion and delays (*1*). Considering that there are undesirable consequences of oversupply as well as undersupply, it is very important to size and operate airport facilities as realistically as possible. Although it may be difficult to design and construct PTBs according to the variable nature of their demand, it is possible to operate them more effectively. This is doubly important with respect to the growth of operating and maintenance costs as the PTB grows in scale and complexity. Factors that contribute to the problem of oversupply and undersupply are summarized.

FACTORS CAUSING THE PROBLEM

The most obvious factor causing the ineffective utilization of airport terminals is traffic peaking. Peaking may be by hour of the day, day of the week, and season of the year. Airport peaking is of course primarily caused by airlines concentrating flights at certain times of the day, days of the week, or seasons of the year. The airline schedule is established based on several criteria, such as the public demand to travel within social hours, the need for arranging connecting services, the utilization pattern of aircraft fleet, and other constraints, for example, night curfews, numerical limitation to night movements, or noise limitations.

The second factor is the current design procedure for PTBs, which determines space requirements according to a broad criterion of average space per person (*2*). For a given traffic level, there is a corresponding space requirement. The traffic level is the forecast demand for a typical hour, that is, typical peak hour passenger (TPHP). Derivation of the TPHP from the existing or forecast data varies among countries, and there is no universally acceptable definition for the TPHP. Even with the standard TPHP, the problem still remains. In theory this is because, assuming the average peak as the 30th busiest hour, the PTB is fully utilized for 1 hour in the year, overutilized for 29 hours in the year, and underutilized for the reminder of the time (8730 hours; there are 8760 hours in a 365-day year) (*3*). In other words, the PTB is overutilized to fully utilized only 0.34 percent of the time each year.

The third factor is that the total system cost is often not visible, particularly those costs associated with operation and support. The visibility problem can be related to the iceberg effect, in which the visible parts are design and construction costs and the remainder (under the water) are operating and maintenance costs. Therefore, the operating cost of PTBs has been almost always ignored in the planning and design process.

The fourth factor is that, in spite of a sensitive relationship between physical planning and operational planning, the analysis of these two is not done early enough. To increase the efficiency of the PTB, two main concepts should be considered in concert: design and operation (*4*). The result of ignoring one of these two concepts would be an inefficient terminal. The combination of a poorly designed PTB with an excellent operational plan may operate well, whereas an excellently designed PTB with a poor operating plan may result in a poorly operating terminal.

The fifth factor associated with the airport PTB design and operation is the month-to-month uncertainty of the airline industry. This creates situations in which terminals designed for one type of operation are forced to operate under a completely different situation because of the bankruptcy of a major airline, and situations in which one carrier is replaced by another carrier with very different scheduling or types of passengers, that is, international versus domestic or hub versus origin and destination operations (*5*). This uncertainty can sometimes render even well-conceived designs inefficient or inappropriate.

However, with the costs and difficulties in modifying the infrastructure to keep pace with the air traffic changes, it would be nec-

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essary for airport planners to (a) favor a flexible design, (b) prepare an operational plan for different scenarios, and (c) allocate the resources based on the variable nature of demand. One approach to this problem of misallocation of resources is explored in this paper by investigating the application of resource allocation and flow management and control theories to the operation of the PTBs. The hypothesis holds that by applying a flow management and control tool, the resources can be allocated to the variable demand in such a way as to minimize the operational and maintenance cost of the PTB from an airport authority's point of view.

IDEAL OPTIMIZATION PROCEDURE

The PTB is a collection of components to facilitate the transfer of passengers and their baggage from groundside to the airside, or vice versa, and sometimes between airsides. These components are considered as existing resources that are to be utilized based on the traffic demand. Since the demand on the terminal system is stochastic and variable, the utilization of resources should also be variable. Thus, based on the concepts of resource allocation, flow management and control, and the dynamic function of the PTB, an ideal optimization procedure can be developed. The ideal methodology of the proposed optimization procedure is indicated in Figure 1. The process consists of three basic parts, that is, the operation of PTB, an optimization model, and a flow management and control model. Within the operational process, passengers will pass through the PTB according to their prespecified schedules and some operational guidelines. The optimum value of required resources would be found based on the demand placed on the system and performance measures by using an optimization model. These values would be allocated to different segments of the PTB that perform different activities based on some flow management and control techniques. If the resources were allocated as they were found from the optimization model, then the output would be minimum operational and maintenance costs for the PTB at different levels of performance. In the following sections, the theoretical optimization model is formulated, a more practical optimization procedure is developed, and a new object-oriented simulation model is discussed to take the place of a real terminal building.

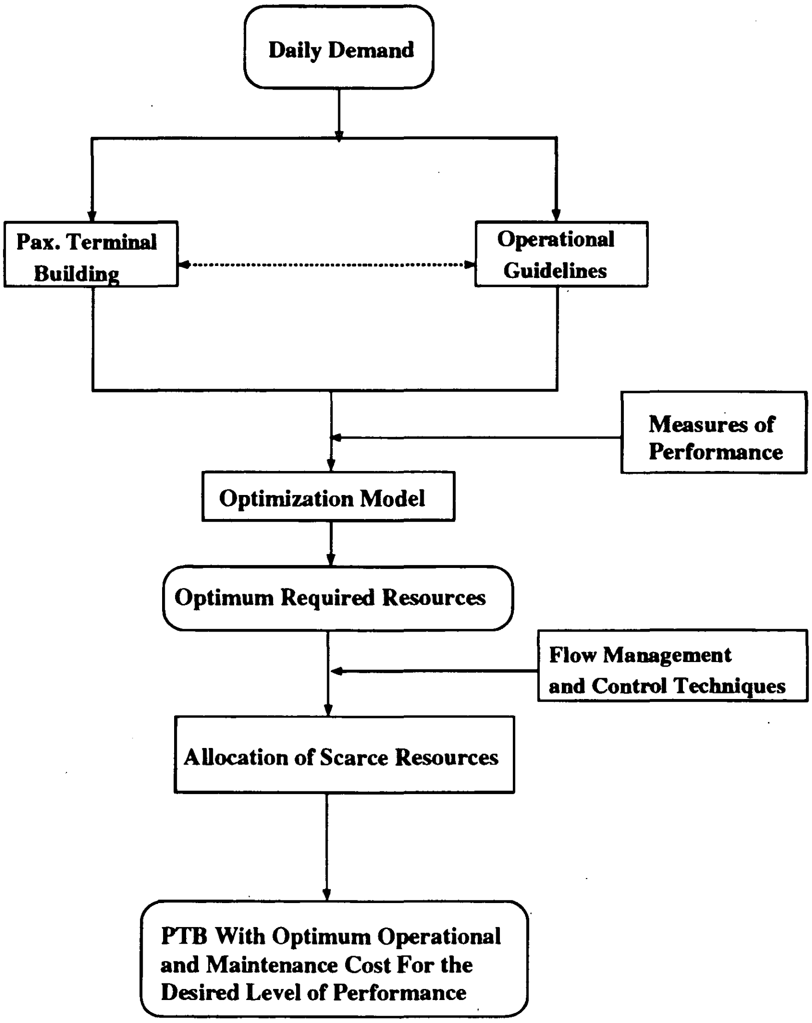


FIGURE 1 Ideal procedure of optimum PTB resource utilization.

Theoretical Analysis

As mentioned earlier, the PTB is a dynamic system mainly consisting of two types of entities, that is, resources and objects (passengers). To optimize the utility of the system, one may deal with either resources or objects or both. In this research, resource allocation theory is used as the basis of the optimization model. In resource allocation theory a fixed amount of resources are allocated to a series of activities with variable demand in such a way that the objective function under consideration is optimized. The resource allocation problem is generally formulated as follows:

$$\begin{aligned}&\text{Minimize } f(x_1, x_2, \ldots x_n)\\ &\text{Subject to: } \textstyle\sum_{j=1}^{n} x_j = N,\\ &x_j > 0, j = 1, 2, 3 \ldots, n\end{aligned} \tag{1}$$

That is, given one type of resource, for example, space whose total amount is equal to N, we want to allocate it to n service locations (segments of PTB) which serve an uncertain number of customers so that the objective value becomes as small as possible. The objective function in general form, that is, Equation 1, cannot be used in practical situations. A special objective function for this research problem was developed as follows:

$$\begin{aligned}&\text{Minimize } \textstyle\sum_{j=1}^{n} c_j(x_j)\\ &\text{Subject to: } \textstyle\sum_{j=1}^{n} x_j \le N,\\ &x_j > 0, j = 1, 2, 3 \ldots, n\end{aligned} \tag{2}$$

where

$c_j(x_j)$ = expected cost at segment j when x_j is allocated to j,
x_j = resource for allocation, for example, space,
n = total number of service locations inside the PTB, and
N = total amount of available resource.

The main objective in Equation 2 is to minimize the expected cost function. The difference between Equations 1 and 2 is that in Equation 2 not all of the resources need to be allocated. The expected cost at each location is a function of allocated resources. As mentioned earlier, there are two types of costs associated with the allocation of resources, that is, oversupply and undersupply cost. Moreover, allocation of resources depends on the demand placed on the facility. As a result, the expected cost is also a function of demand. The demand at each location is uncertain and depends mainly on the flight schedule. Taking all the variables into consideration, the total expected oversupply and undersupply cost for the PTB is found as follows:

Assume that y is the demand variable at each service location and $p_j(y)$ is the probability mass function for variable y at segment j. This means that the probability of having y units of demand at segment j is $p_j(y)$. It is also assumed that each unit of demand needs θ_j units of resource at segment j, for example, the amount of space that each passenger occupies. If x_j is the resource allocated to segment j, and α_j is assumed to be the unit cost of oversupply at location j, then the oversupply cost at this location is as follows:

$$\alpha_j \sum_{0}^{\delta_j} (x_j - \theta_j y) p_j(y) \tag{3}$$

where $\delta_j = \text{int}(x_j/\theta_j)$.

If the resources allocated to segment j were less than required, then there would be an undersupply cost. Following the same process and assuming β_j as the unit cost of undersupply, the expected undersupply cost would be:

$$\beta_j \sum_{\delta j}^{y} (\theta_j y - x_j) p_j(y) \tag{4}$$

where Y = maximum expected demand for segment j.

Therefore, the total over and undersupply cost associated with the allocation of x_j resources to segment j is the sum of two preceding cost elements as follows:

$$c_j(x_j) = \alpha_j \sum_{0}^{\delta j} (x_j - \theta_j y) p_j(y) + \beta_j \sum_{\delta j}^{y} (\theta_j y - x_j) p_j(y) \tag{5}$$

where

$c_j(x_j)$ = expected cost at segment j,
x_j = resource for allocation,
$p_j(y)$ = probability mass function of demand,
θ_j = resource allocated to each demand unit,
α_j = unit cost of oversupply,
β_j = unit cost of undersupply, and
$\delta_j = x_j/\theta_j$.

Since the PTB system consists of several service locations for which resources should be allocated, the total expected oversupply and undersupply cost for the whole system would be as follows:

$$\begin{aligned}C_T = \sum_{j=1}^{n} c_j(x_j) = \sum_{j=1}^{n} \Big[\alpha_j \sum_{0}^{\delta j} (x_j - \theta_j y) p_j(y)\\ + \beta_j \sum_{\delta j}^{y} (\theta_j y - x_j) p_j(y)\Big]\end{aligned} \tag{6}$$

However, if the resources and demand were assumed to be divisible, then x_j and y are continuous variables that can take any non-negative real values. In this case following the same procedure of indivisibility, the total cost function for segment j would be as follows:

$$c_j(x_j) = \alpha_j \int_{0}^{\delta j} (x_j - \theta_j y) dF_j(y) + \beta_j \int_{\delta j}^{\infty} (\theta_j y - x_j) dF_j(y) \tag{7}$$

where $F_j(y)$ = cumulative distribution of demand at segment j.

If μ_j is defined as the mean of F_j, then by using the principles of probability theory, the preceding equation would finally simplify to:

$$c_j(x_j) = \beta_j \theta_j (\mu_j - \delta_j) + (\alpha_j + \beta_j) \theta_j \int_{0}^{\delta j} F_j(y) dy \tag{8}$$

Considering that $\delta_j = x_j/\theta_j$, then the derivative of the preceding equation with respect to x_j is as follows:

$$c_j(x_j) = -\beta_j + (\alpha_j + \beta_j) \theta_j F_j(x_j) \tag{9}$$

From Equation 8 and its derivative (F_j is increasing) it is clear that the function is convex with respect to variable x_j, which means that there is a minimum point in the function (Figure 2).

According to Figure 2, the operation cost is high before reaching its optimum point. This is referred to as undersupply cost, which is the cost of physical and psychological discomfort perceived by passengers because of the lack of adequate resources. The real value of these costs to the airport operator is difficult to estimate. In some cases they may be roughly approximated by the frequency of com-

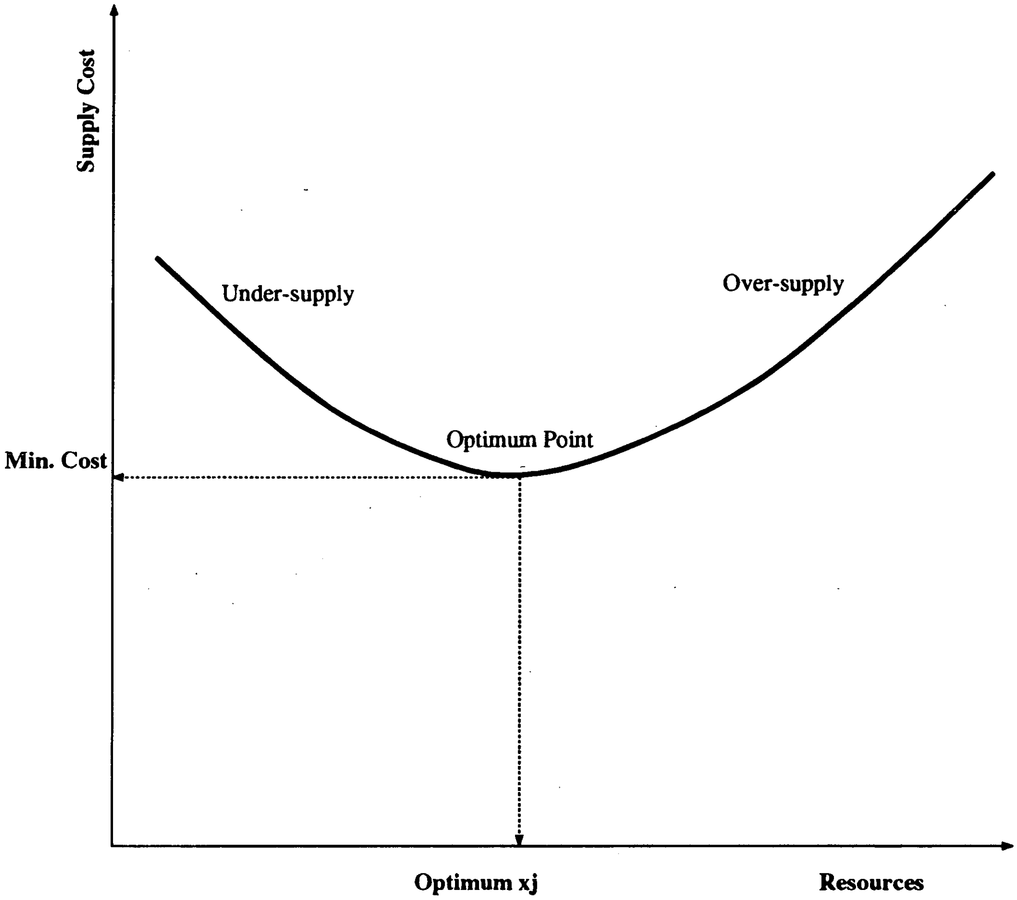


FIGURE 2 Cost function of PTB segments with respect to resource value.

plaints and critical journalism or the loss of potential customers. The operational cost increases right after the optimum point. This is the oversupply cost, which is the cost of providing resources beyond what is required. Having information about operational and maintenance expenses, this unit cost is possible to estimate. However, the objective function would be a series of nonlinear separable convex functions that have to be optimized. If the values of α_j, β_j and the demand function were known, then there would be some analytical approaches to solve such problems as Equation 1, in which the total amount of resources would be allocated (*6*). The objective function of this research problem is more complex than the conventional ones because of the fact that the sum of allocated resources could be less than or equal to the maximum resource available. Moreover, due to the stochastic nature of passenger arrivals and departures at the PTB, no specific mathematical function can represent the actual demand on the system at each instant of time. Therefore, demand function may be found either through an exhaustive data collection exercise for a long period of time, or by using a simulation approach.

PRACTICAL OPTIMIZATION PROCEDURE

The ideal process was believed to be difficult to apply in a real terminal for the time being. Therefore, the three parts of the ideal process were modified to develop a more practical procedure (Figure 3). In the first part of the practical procedure, the PTB is simulated to perform as a real terminal. The simulation model will be discussed in the next section. The simulation is run for a number of days or weeks, and the population statistics are collected for each segment of the PTB during the whole running period. These statistics are analyzed to arrive at the probability mass function (PMF) of demand for each PTB segment. To be as realistic as possible, the operating day is divided into short time periods, for example, 1 hour, and the PMF for each time period is obtained. The PMFs and the values of α and β are used as input to the second part of process, that is, the optimization algorithm. The optimization algorithm determines the optimum value of required resources for each segment at each instant of time. The output of optimization algorithm is a variable time-resource diagram.

The sum of optimum resource values from all segments multiplied by the unit cost of providing resources is the optimum cost of operating the PTB at each instant of time. If all the conditions are met, the operational and maintenance cost will be a function of demand distribution. However, in the third part, it is recommended that the results of the optimization procedure be implemented on the site by some sort of flow management and control technique. The existing resources and the traffic flow should be managed in such a way as to provide a diagram as close to the optimum time-resource plan as possible. The details of the optimization algorithm and the flow management and control model are ongoing research. The results will be the subject of our next paper.

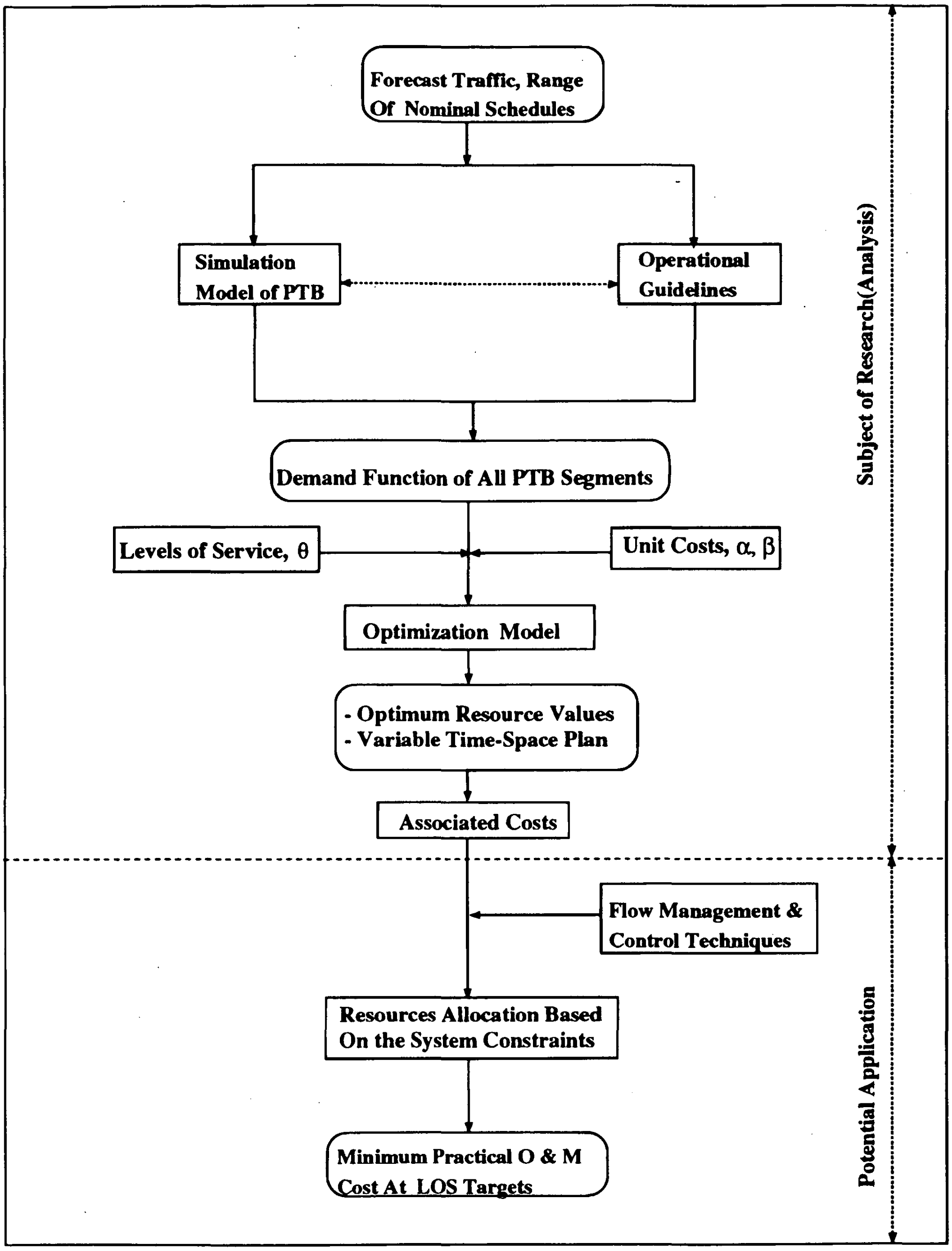


FIGURE 3 Practical procedure of optimum PTB resource utilization.

PTB Simulation Model

Airport terminal simulation models have been developed for more than 30 years (*7*). Through the literature review on existing and currently used simulation models, it was found that models currently available do not respond to the types of issues associated with PTB operation and management. They require extensive programming to fit with any specific configuration of a terminal, take a long time to process any particular run, and require too much detailed information for every run (*8*). An additional problem with currently used simulation models is occasional failures to address important aspects of terminal operations (*9*).

Recently, because of new developments in software technology, there has been a lot of interest to use object-oriented programming (OOP) in PTB simulation. The object-oriented approach has some advantages over conventional languages used in simulation. In summary, the OOP approach is capable of providing immense programming flexibility, greater reduction of input requirements, ease of operation, and user friendliness (*10,11*). OOP also provides fully interactive execution with a high degree of animation and graphics capabilities. The models in the OOP concept are built in terms of real world components of the system, as opposed to reducing components to a series of mathematical relationships and writing computer programs to invoke those relationships. In spite of all of its advantages and interest in the airport industry, a PTB simulation model using OOP is not yet publicly available.

However, for this research, a comprehensive search was undertaken to find the most recent and state-of-the-art simulation tool. A new object-oriented graphical modelling environment, the SES/workbench from Scientific and Engineering Software Incorporated, was found and used to simulate PTB operation (*12*). The SES/workbench is an integrated collection of software tools for simulation and evaluation of complex systems, such as computers, large software systems, data communication networks, and microprocessors. The SES/workbench consists primarily of SES/design, SES/sim, and SES/scope. The graphical representation of the system is built by using the design interface module, SES/design, in which objects are created to represent the various components of the system. The graphical representation is converted to an executable simulation model by SES/sim, a translation and simulation module based on the C and C++ programming languages. Finally SES/scope is an animation module that provides the ability to observe and debug an executing simulation model.

In summary, an SES/workbench model is composed of one or more submodels, each represented by an extended directed graph. The basic components of a graph are nodes, arcs, transactions, and resources. Transactions are entities that flow from node to node along the arcs. Each transaction represents a process to be executed. Each transaction may carry with it an arbitrary user-defined data structure. Each node in a model represents the manipulation, for example, allocation, or release of a physical or logical resource, or some other processing step in a transaction's life. Each arc connects two nodes and is directed from one node to the other. It represents a path along which a transaction may flow from one node to another. Each resource represents some physical or logical component for which transactions compete.

Simulation Model Framework

The PTB simulation model (PTBSIM) is designed to predict the movement of passengers, greeters, and well-wishers for a given terminal design and a candidate commercial aircraft schedule. Throughout the model development every effort was made to keep the model as simple and user friendly as possible. Although the model was developed based on a given terminal design, it is very easy to adjust the model for any type of PTB due to its object-oriented aspect. One can easily change, delete, or copy any node, arc, or submodel to get the desired design. The only required input to the model is an aircraft schedule, which can be entered using any text editor. The aircraft schedule is used to generate passengers and nonpassengers entering the PTB. The operating day is divided into equal time increments, for example, 1 minute long. It should be noted that the size of increments can be any value, for example, from milliseconds to hours.

The PTBSIM was developed as one main module, consisting of six submodels, that is: generate_planes, generate_arrive_pax, generate_depart_pax, process_arrive_pax, process_depart_pax, and concourse. In addition, several functions were developed to define the workload and transaction routing. These functions and some parameters are declared in the three declaration nodes. A brief description of declaration nodes and submodels follows.

In the main_declaration node, two structures are declared as plane and passenger. These two structures consist of a collection of variables (information) which each plane or passenger should carry throughout the model. The structures are declared as "unshared," meaning that each passenger will preserve its own copy of data, including flight number, gate, departure time, and so forth, while passing through different segments of the PTB. Several functions for transaction routing and passenger arrival time sorting are declared in the functions_decs node. In the param_declaration node, several input variables are declared as parameters to include parameters in the model. Parameters can be changed during the runtime, which makes the model user friendly.

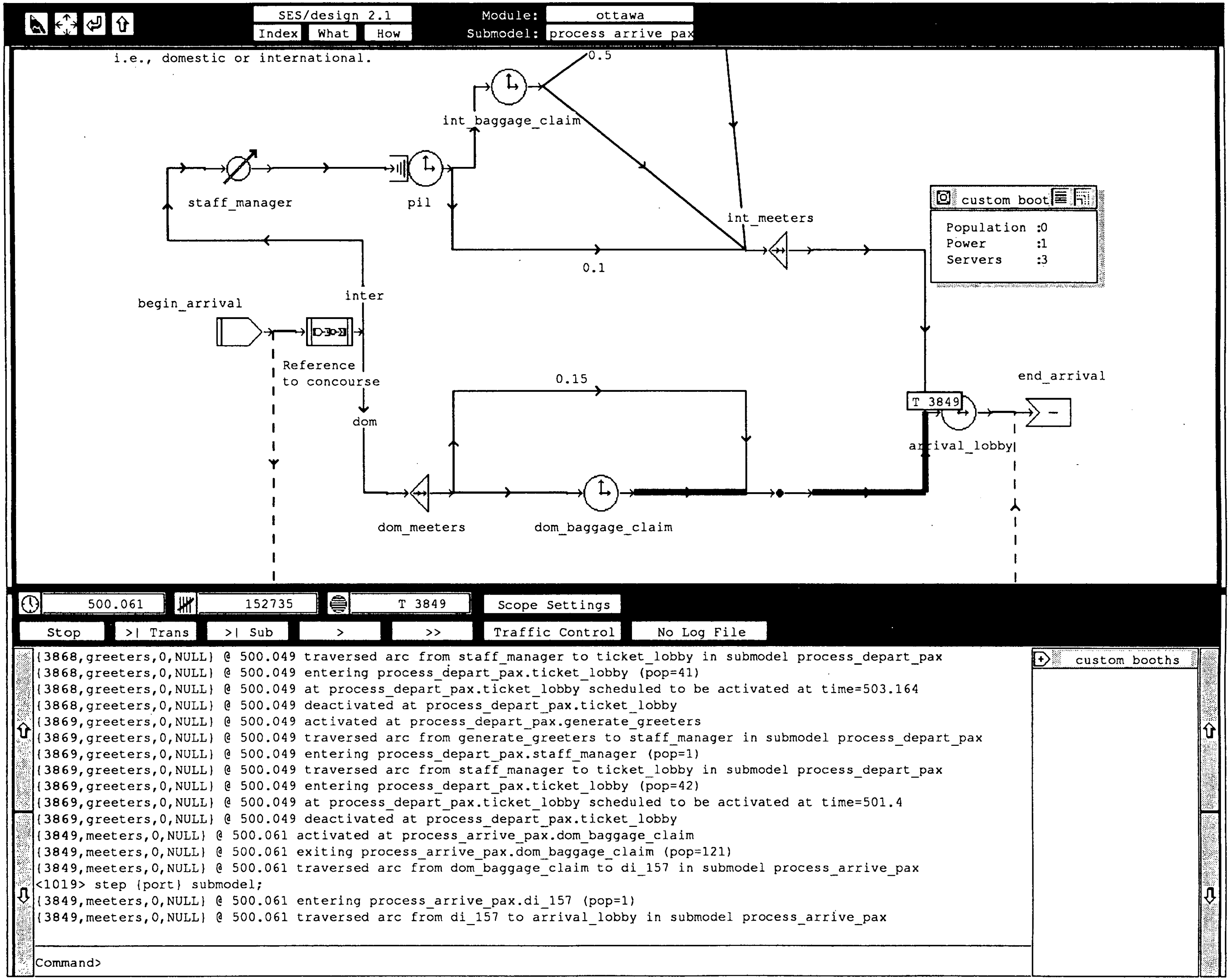
The generate_planes submodel is the planeload-generator submodel. A transaction, "seed," is generated, reads each line of the schedule, and generates another transaction called "plane." The plane transaction is routed to either generate_arrive_pax or generate_depart_pax according to its sector, that is, arrival or departure.

The generate_arrive_pax submodel generates arriving passengers. The plane transaction enters the submodel and waits in the delay node for its event time. When the transaction reaches its event time, it generates the number of passengers according to a normal probability distribution, with the mean of average deplaning rate defined by the user. The accumulated number of passengers generated for each increment is compared with the total number of passengers of each aircraft. Once the array of passenger transactions is generated, the plane transaction sends them to the submodel process_arrive_pax.

The submodel generate_depart_pax generates the enplaning passengers and sends them for processing. The plane transaction enters the submodel and after reaching its event time generates the time that each departing passenger arrives at the airport according to a triangular probability distribution. In the triangular distribution, the minimum is defined when the first passenger of the flight arrives at the PTB, the maximum as the time when the last passenger of the flight arrives at the PTB, and mode as the time when the maximum number of passenger arrive at the PTB.

The submodel process_arrive_pax models the activities of deplaning passengers and meeters. Passengers unloaded from the aircraft go to the submodel concourse, to be explained later. Passengers coming out of the submodel concourse will be routed according to their region, that is, domestic, international, and so forth. On arrival of domestic passengers to the baggage claim area, meeters will be generated according to a uniform probability distribution ranging from 0 to 2. The international passengers will go through the preliminary inspection lines (PIL) (Canada Customs and Immigrations), secondary customs, immigration, the baggage claim area, and the arrival lobby. The service times for all these activities are drawn from some probability distributions in which mean and standard deviation are based on historical data (*1,13,14*).

The process_depart_pax submodel models the behavior of enplaning passengers and well-wishers. Departure passenger transactions are accompanied with the well-wishers. Well-wishers are generated from an integer uniform probability function. Almost all the passengers and well-wishers go through the ticket lobby. A percentage of passengers either are preticketed or go to the express check. Each major airline and its allied carriers is represented by a service node with some number of servers. Passengers are directed to the service nodes according to their flight numbers. Depending on how much time is left for each passenger before departure, the passengers may stay in the waiting and concession area. If the time left for the passengers is too short, then the passengers will experience only the walking-time delay. Passengers and their companions proceed to the security booths and gates through corridors or some vertical transportation facilities, such as escalators, elevators, or



Population :0
Power :1
Servers :3

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{3868,greeters,0,NULL} @ 500.049 traversed arc from staff_manager to ticket_lobby in submodel process_depart_pax
{3868,greeters,0,NULL} @ 500.049 entering process_depart_pax.ticket_lobby (pop=41)
{3868,greeters,0,NULL} @ 500.049 at process_depart_pax.ticket_lobby scheduled to be activated at time=503.164
{3868,greeters,0,NULL} @ 500.049 deactivated at process_depart_pax.ticket_lobby
{3869,greeters,0,NULL} @ 500.049 activated at process_depart_pax.generate_greeters
{3869,greeters,0,NULL} @ 500.049 traversed arc from generate_greeters to staff_manager in submodel process_depart_pax
{3869,greeters,0,NULL} @ 500.049 entering process_depart_pax.staff_manager (pop=1)
{3869,greeters,0,NULL} @ 500.049 traversed arc from staff_manager to ticket_lobby in submodel process_depart_pax
{3869,greeters,0,NULL} @ 500.049 entering process_depart_pax.ticket_lobby (pop=42)
{3869,greeters,0,NULL} @ 500.049 at process_depart_pax.ticket_lobby scheduled to be activated at time=501.4
{3869,greeters,0,NULL} @ 500.049 deactivated at process_depart_pax.ticket_lobby
{3849,meeters,0,NULL} @ 500.061 activated at process_arrive_pax.dom_baggage_claim
{3849,meeters,0,NULL} @ 500.061 exiting process_arrive_pax.dom_baggage_claim (pop=121)
{3849,meeters,0,NULL} @ 500.061 traversed arc from dom_baggage_claim to di_157 in submodel process_arrive_pax
<1019> step {port} submodel;
{3849,meeters,0,NULL} @ 500.061 entering process_arrive_pax.di_157 (pop=1)
{3849,meeters,0,NULL} @ 500.061 traversed arc from di_157 to arrival_lobby in submodel process_arrive_pax

Command>
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FIGURE 4 **Illustration of SES/design and SES/scope window.**

moving belts. Only passengers are allowed to pass the security and to go to the concourse. It should be noted that the number of servers in each service node, that is, PTB personnel, is dynamically managed over time by a set node called staff_manager.

The concourse submodel is a waiting area with several gates. Both arrival and departure passengers will go through the concourse area. The arrival passengers experience a delay time equal to their walking distance divided by their walking speed, and the departure passenger enters the concourse and waits until the final boarding call. Therefore, each passenger will experience a different amount of delay time. The reason for making the model into six submodels is to make the model flexible enough for possible adjustments of specific PTBs.

PTBSIM Evaluation

When the basic layout of the model was constructed, the SES/scope was used to calibrate the model. SES/scope allows the modeller to interact with, control, and debug the model while it is running. It also allows one to watch an animated display of the model's execution and to debug the model should it behave in unexpected ways. One can interact with the animation of a running model through the SES/scope window below the SES/design window. An example of the window is indicated in Figure 4. All the trace messages and other information about the model's state are displayed in the SES/scope window. One can enter control commands at the command line prompt below the SES/scope window. At the top of SES/scope window is a banner containing several buttons that are used to control various animation parameters, and fields that display information about the current state of the model.

While SES/scope is active, one may examine specification forms, defined for the nodes in the graph, displayed in the SES/design window. In the case of any unexpected behavior of the model, the specification form may be checked for tracing the problem. After the debugging process, one may calibrate the model using the animation capability. SES/scope provides a detailed animation of the model events as the model runs. Modellers also have control over the events that they choose to see animated. Some of the events that can be animated are transaction movement, transaction tracking, transaction creation and destruction, service and delay nodes, and queue entry and exit.

For example, as a passenger (transaction) flows through the PTB, for example, traverses arcs and enters nodes, it is represented by a rectangle containing a "T" (for transaction) followed by the transaction identification number (Figure 4). The most recently traversed arc is thickened considerably. This permits one to observe visually the paths that specific transactions follow as they flow through the model. Modellers control the scope of animation by using the buttons and defining them according to their own needs. For example, one may choose to animate a specific category of passengers, a specific service node, or a submodel. Using the SES/scope, the debugging process was done and the PTBSIM was finetuned based on data obtained from the Macdonald-Cartier International Airport in Ottawa, Canada.

The general objective of the validation procedure for PTBSIM was to demonstrate the extent of agreement between model outputs and corresponding data obtained at the airport. Data observed for this purpose are time series of flow and queue length at passenger processing facilities. Data were collected by stationing observers at several locations throughout the PTB for simultaneous observation of the population at each processing unit. The model is also capable of producing time series data for direct comparison with field observation. The outputs from the PTBSIM and observed data versus time were plotted on the same pair of axes for visual comparison.

The model provided generally good representation of those facilities surveyed, as illustrated in Figure 5. More complete discussion

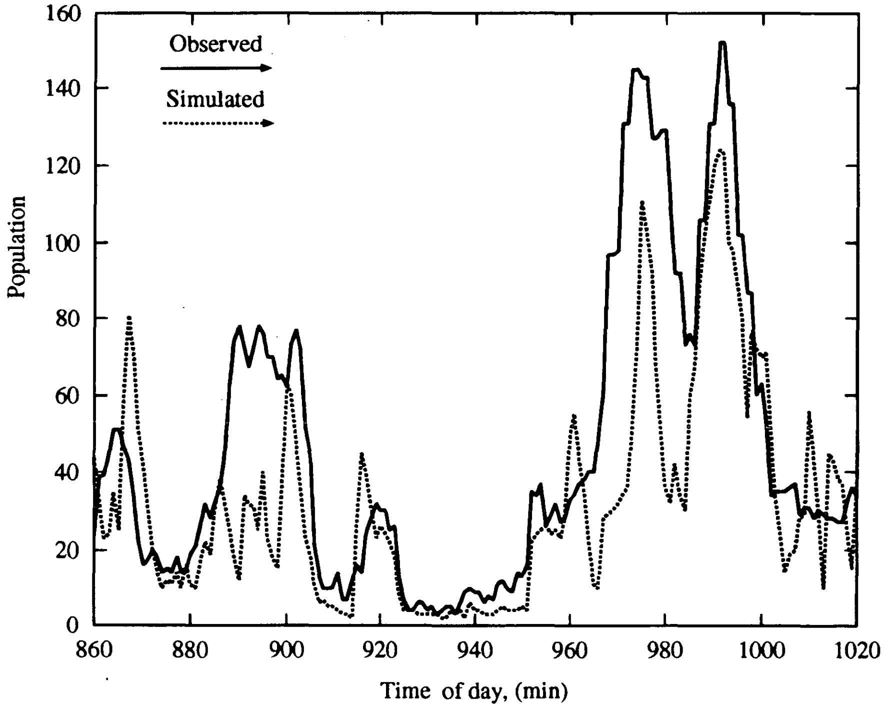
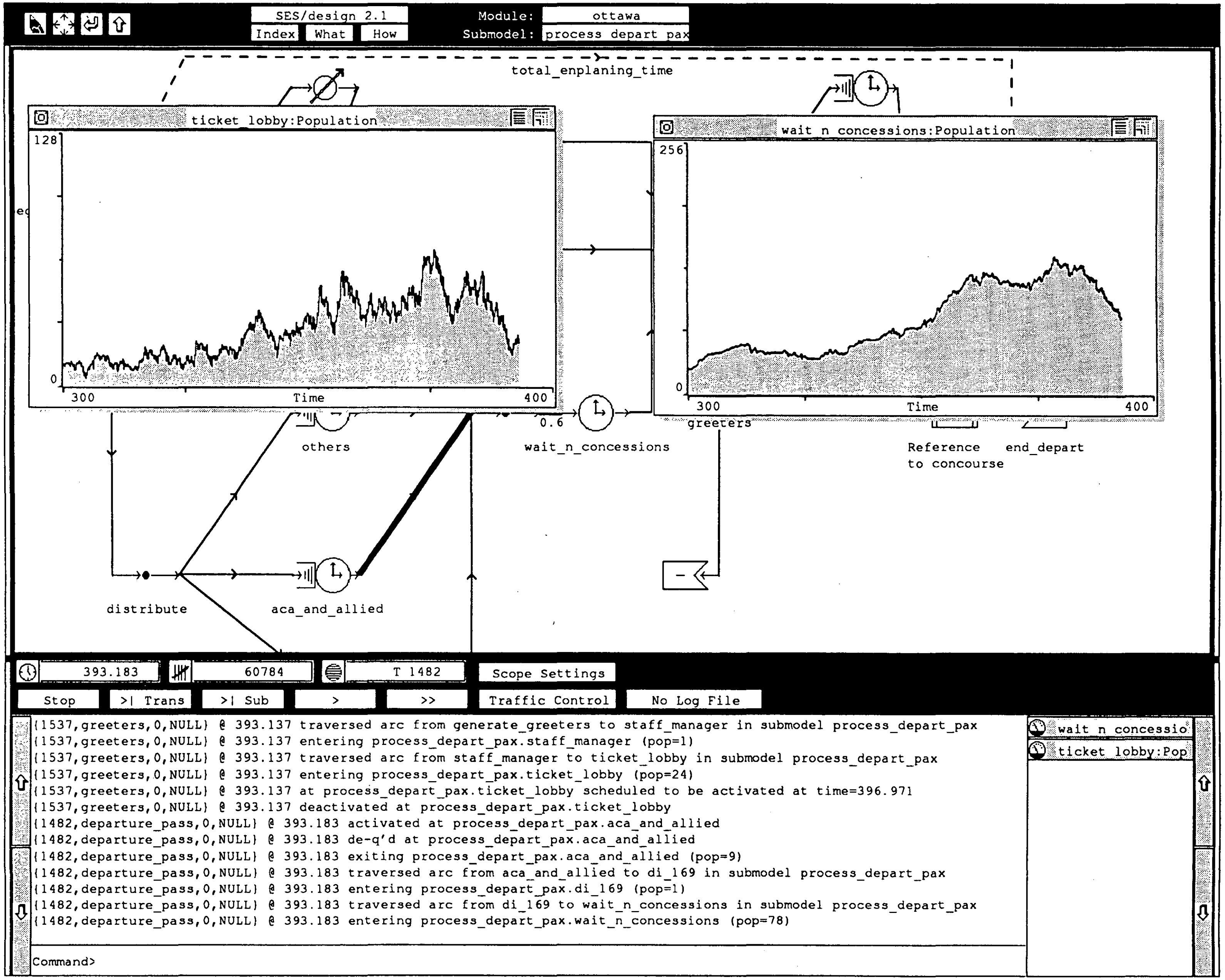


FIGURE 5 Comparison of simulation outputs and observed data at baggage claim area.



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{1537,greeters,0,NULL} @ 393.137 entering process_depart_pax.staff_manager (pop=1)
{1537,greeters,0,NULL} @ 393.137 traversed arc from staff_manager to ticket_lobby in submodel process_depart_pax
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{1537,greeters,0,NULL} @ 393.137 deactivated at process_depart_pax.ticket_lobby
{1482,departure_pass,0,NULL} @ 393.183 activated at process_depart_pax.aca_and_allied
{1482,departure_pass,0,NULL} @ 393.183 de-q'd at process_depart_pax.aca_and_allied
{1482,departure_pass,0,NULL} @ 393.183 exiting process_depart_pax.aca_and_allied (pop=9)
{1482,departure_pass,0,NULL} @ 393.183 traversed arc from aca_and_allied to di_169 in submodel process_depart_pax
{1482,departure_pass,0,NULL} @ 393.183 entering process_depart_pax.di_169 (pop=1)
{1482,departure_pass,0,NULL} @ 393.183 traversed arc from di_169 to wait_n_concessions in submodel process_depart_pax
{1482,departure_pass,0,NULL} @ 393.183 entering process_depart_pax.wait_n_concessions (pop=78)

Command>
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FIGURE 6 Real-time graphic illustration of statistical results.MDNM/.

on the results of simulation can be found elsewhere (*15*). The model can also be validated in some degree through SES/scope. Running in SES/scope, one can see the graphic illustration of some statistics, such as population, queue length, and so forth. Figure 6 indicates the population statistics against time for several segments of the PTB. The modeller would be able to change the parameters and observe the consequences graphically. The graphs can be zoomed for more detail illustration.

Although the visual approach indicates an agreement, the extent to which the model can replicate the existing situations is another important aspect to statisticians. PTBSIM also outputs a list of statistics, for example, mean, standard deviation, maximum, and minimum for some parameters defined throughout the model, such as population, queue length, waiting time, and utilization. These statistics are very useful for overall performance evaluations of the model. In addition, the Statistical Package for Social Science (SPSS), a program utilizing the least square method, was used to find the degree of correlations between the observed and simulated values (*16*). By looking at the results and taking into account the stochastic nature of passenger activities, it appears that the model can reasonably predict the behavior of passengers in the PTB. As already mentioned, by changing some input variables, any terminal building can be modeled. Moreover, in a specific PTB, any operational plan can be generated and tested very easily. Therefore, the PTBSIM is not only a simulation tool but an evaluation tool as well.

Conclusions and Future Research

The optimization procedure described in this paper can be used as a utilization plan to operate the PTB at its minimum total oversupply and undersupply cost. The procedure can also be used as a short- or long-term planning tool. Given a nominal aircraft schedule, the planner would be able to simulate the basic activities and services required for a passenger terminal. Using the statistics obtained from the simulation as input to the optimization model, a modeller will get a variable time-resource diagram. The diagram could be daily, weekly, monthly, or yearly depending on the accuracy of the analysis. The designer can use these diagrams to prepare a more flexible and efficient physical layout. Therefore, there would be a better association between the physical and operational plans at the early stages of planning.

The idea of flow management and control can respond to some real-time events which may happen due to an uncertain economy, bankruptcy or replacement of a carrier, traffic demand changes, or even natural factors such as inclement weather.

Using the PTBSIM, the airport operator would be able to place the demand on the PTB system and observe its operation. The operator can also interactively test the PTB operation under different load conditions or operational plans. PTBSIM can also be used as an operations tool for the operating staff to help them to maintain a reasonable level of service through the PTB.

The use of SES/workbench to simulate the PTB instead of using more conventional simulation languages reduced the simulation time substantially without reducing the overall accuracy of results.

However, to implement the practical optimization procedure, more research is needed. At present, research is proceeding to develop a heuristic optimization algorithm that can be combined with the simulation model. The procedure will be tested on different passenger terminals and the results will be compared.

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