PASSENGER TERMINAL DESIGN

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Abstract

The standard procedures for sizing the spaces for passenger activities in airport terminals are unsatisfactory in that they easily lead to expensive errors. The essential difficulty lies in the nature of the process, and in particular with the several formulas which specify the area per passenger in different parts of the building. The process and these formulas are insensitive both to the variations in the operational characteristics of terminals and to the overall variability in the level and nature of the traffic.

This paper presents practical procedures for incorporating stochastic considerations into terminal design, based both on theory and extensive experience internationally at major airports. The approach builds upon detailed consideration of the sequences of flows of the passengers, their likely dwell-time in each facility, and their psychological response to the configuration of the spaces.

The overall objective is to create flexible designs that use space efficiently under the broad range of conditions that may prevail. It entails an iterative process of exploring the response of design options to different patterns of loads. This approach invites computerized models of the performance of terminals with spread-sheet like capability to answer what-if questions rapidly.

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Introduction

Passenger terminals at airports are very expensive, both absolutely and per gate for aircraft. As of 1990, for example, the new International Terminal Building (ITB) for Sydney will cost about US$ 200 million, or 25 million per gate; the central terminal for the new Milano/Malpensa airport about US$???? million or ???? per gate. The cost of fully fitted out space in airport terminals is easily US$ 2000 per sq.m. (about US$ 200 per sq.ft.).

Mistakes are correspondingly costly. For example, the simple, avoidable errors in the original design of the interior spaces for the Air France Terminal at Paris/Roissy (de Neufville and Grillot, 1982) had an estimated price tag of around US$ 75 million in 1990 terms.

Overdesign, either as a simple expedient for avoiding future congestion or for the aesthetic of open spaces, can also be most expensive. For example, the decision to make the central corridor of the 180 m. long finger pier of the new two-level Sydney ITB 12m. wide, instead of a feasible 6m., implied an extra capital cost of about US$ 4 million.

Cost-effective, efficient design of passenger terminals is thus important, especially in view of the number of new facilities projected. Unfortunately, the standard design procedures for airport terminals are based on handbook formulas insensitive to the realities of each situation. These crude approaches cannot be considered adequate to the task. Worse, it is our observation that the formulas are easy to misunderstand and thus frequently misapplied.

A more scientific approach is required, one that incorporates a realistic appreciation both of the dynamics and behavior of sequences of queues, and the the psychology of crowds in such situations. The design process should also recognize that, as we experience deregulation, the elimination of frontier controls, and new airline organizations, the actual levels and needs of future traffic may be quite different from anticipated.

To develop this approach, this paper first examines the nature of the current design process and identifies the three elements most in need of improvement. It then proposes how each of these elements could be handled better, and concludes by integrating these suggestions into a comprehensive design process for passenger terminals.

Typical Design Process

A more or less standard process has evolved over the years for the design of passenger terminals at airports. It consists of four steps:

1) Forecasting traffic levels for peak hours;
2) Specification of level-of-service standards;
3) Flow Analysis and determination of server and space requirements; and
4) Configuration of servers and space.

The review of these steps provides the basis for understanding why and how the curent design process should be changed.

Forecasting of traffic levels at peak hours: The objective of this exercise is to produce highly detailed, peak-hour demand scenarios for the design day many years ahead. These figures provide the basis for the actual design. It is a most speculative enterprise.

This forecasting process normally first estimates aggregate traffic for the "target year" for which a new, expanded or modified terminal is being designed. This aggregate forecast, in turn, is converted into a further estimate of traffic for the "design day", normally taken to be as the 30th. or 40th. busiest day of the year, or as something such as the "average weekday of the peak month". This is usually done using a set of "conversion factors", partly based on historical data. Note that the target year is arbitrary, generally a round number; and that the use of conversion factors assumes that the pattern of traffic over twenty years or so is predictable, contrary to our current experience.

Design exercises furthermore frequently develop hour-by-hour traffic scenarios for the design day, down to the level of a specific schedule of flights, for which assumptions must be made concerning the type of aircraft involved, their origin or destination, load factors, percentage of transfer or transit passengers, etc. When one recognizes the difficulty of predicting a flight schedule six months from now, it is clear that its forecast for twenty years hence is close to divination.

Forecasts are in any case demonstrably inaccurate. This has been repeatedly shown by retrospective analyses comparing forecasts to what actually occurred (U.S. Office of Technology Assessment, 1982; Ascher, 1978; de Neufville, 1976). The six-year forecasts of the U.S. Federal Aviation Adminstration have been, over the years, over 15 to 20 percent different from reality about half the time.
Figure 1 illustrates the situation for aggregate national forecasts. The situation gets worse for more detailed predictions, as one moves to individual airports and then to subsections of the airport activities. It is well known that the higher variability of the detailed forecasts tend to cancel out as they are aggregated. In any event, no confidence should be placed in the detailed forecasts usually generated by the standard design process for airport terminal buildings.

Specification of Level-of-Service Standards: The objective here is to specify explicitly level-of-service (LOS) standards for waiting times and space allocation (i.e., the number of square meters per space occupant) at the processing facilities, the holding areas and the passageways of the terminal. These standards provide the basis for translating the forecasts into an architectural program.

To specify the LOS standards, the designer must work closely with the airport owner or operator. Higher standards imply more space and cost, and these have to be made compatible with the client's financial objectives. The level of detail at which this step is carried out varies greatly from airport to airport, and the results may also be very different.

The LOS for space are usually defined in terms of "space conversion factors" giving the appropriate space per simultaneous occupant. The best-known and most widely used factors are listed in Table 1. These were originally developed by Transport Canada during the early 1970's, and subsequently adopted jointly by the International Air Transport Association (IATA) and the Airport Associations Coordinating Council (AACC), (AACC/IATA, 1981). As can be seen, the factors span a considerable range, from the LOS=A (best) to LOS = E (worst). A number of other organizations, such as British Airports, the Aeroport de Paris, and the Australian Department of Housing and Construction (1985) have developed their own space conversion factors. These are all usually single-valued for any activity and LOS, and roughly equal to those in Table 1.

Similar factors have been developed for persons flowing through passageways or corridors (Fruin, 1971). They are stated in terms of passengers per foot width per minute (PFM), with typical values of around 16 (LOS = C) and 12 (LOS = D).

Table 1: Level of Service Standards (sq.m. per occupant)
Source: AACC/IATA (1981)

Sub-System	Level of Service Category				
	A	B	C	D	E
Holding with Bags:					
Check-in	1.6	1.4	1.2	1.0	0.8
Bag Claim Area					
Holding w/o Bags:					
Holdroom	1.4	1.2	1.0	0.8	0.6
Pre-Inspection					
Wait/Circulate	2.7	2.3	1.9	1.5	1.0

While the specific values of the space conversion factors can certainly be disputed, there is little doubt about the soundness of the general principle of allocating space in proportion to the number of people <u>simultaneously</u> in any particular part of the terminal. In practice, however, this application of this principle has been characterized by widespread misinterpretation and lack of insight.

The concept of <u>dwell time</u>, the amount of time people spend in a particular area, is central to determining the number of <u>simultaneous</u> occupants. For instance, if the flow of passengers through a lobby is relatively uniform over time at a rate of 900 per hour, and if their dwell time is 20 minutes or 1/3 of an hour, then the number of people in the lobby at any time is 900 x 1/3 = 300. Space thus needs to be provided for 300 people, not 900. While this should be obvious, it is surprising how often it is misunderstood.

A most common mistake in practice is to disregard dwell time altogether and use the number of peak hour passengers for the design day (often known as "typical peak hour passengers" or TPHP) as the number of simultaneous occupants. In our case, this error would result in the provision of 3 times as much space as needed.

It would seem that much of this confusion stems from a set of guidelines ("FAA Standards", see FAA, 1969) issued a generation ago, which specified space requirements in terms of area per TPHP. See Wright (1984) and Horonjeff and McKelvey (1985) for details.
For example, these guidelines recommend a total of 24.2 sq.m. per TPHP for a domestic terminal, and 39.2 sq.m. per TPHP for an international terminal, with 1.0 sq.m. allocated to the ticket lobby, 3.3 sq.m. to customs, etc.

Clearly, the "FAA standards" were originally developed for a specific set of conditions regarding how long typical domestic or international passengers spend in the terminal, what percentage of them go through the ticket lobby and use the ticket counters, what type of customs procedures are in effect, etc,

etc. Given the major changes that have taken place in airport operations over two decades, the FAA standards are probably inapplicable today, even for the medium-sized U.S. airports from which they were developed. An improved design process for airport terminals thus needs to focus attention on the time passengers actually spend in a space, their dwell time.

A further problem with these standards is that they assume that the space provided for an activity will be useful, no matter how or where it is provided. Implicit in the formula is the idea that the occupants of a space somehow disperse to make use of the entire area. People are not gasses, however, and no such Brownian motion exists for them. The fact is that people tend to congregate in places either because of a focus of attention, such as an information booth or an open check-in counter; or because they perceive them to be convenient, such as the mouth of the baggage shute or the check-in counters in front of the entrance. It thus easily and quite predictably happens that a terminal with enough space by the above criteria, in fact has a number of significant problem areas which make the terminal feel, and thus be, inadequate.

Flow Analysis and Determination of Server and Space Requirements:
There are essentially three ways that have been used to analyse the flows and determine the amount of space and the number of servers required:

1) Formal applications of queuing theory;
2) Graphical analyses using cumulative diagrams; and
3) Detailed computer simulations.

The formal applications of pure queuing theory (e.g., Lee, 1966) have not proven efficient for design. This is because the processes in airports are essentially never in a steady-state condition that can be analyzed; they are almost always undergoing some kind of transient. Furthermore, the queues are often undisciplined.

Graphical analyses of the cumulative arrivals and service (Newell, 1971) have proven most effective in analysing and designing quite specific elements of the terminal such as departure lounges (Horonjeff and Paullin, 1969) or ticket-counters (de Neufville and Grillot, 1982). These solutions presume that the pattern of loads is known: they are thus best for the redesign of a particular space within an existing structure. This approach does not tie in well to the process of designing a complete terminal, since each major alternative is likely to change the pattern of flows into a particular activity area.

Simulations provide the means -- in principle at least -- of investigating the flows throughout an entire building. They have so far, however, generally been unsuccessful because the available computer programs have been virtually impossible to use. Most programs derive from a single architypal program, ALSIM, and require extensive reprogramming to fit with any specific configuration of a terminal; take a long time to process any particular run; and assume that detailed, hour-by-hour forecasts are available (McKelvey, 1989). A designer would be extremely lucky to get this kind of simulation to model a handful of possible scenarios.

Configuration of Servers and Space: The final design integrates the above steps. What happens in practice is that the design team takes a specific level of flows for a peak hour (often associated with a particular schedule, such as the arrival of several Boeing 747-400's); associates these with level-of-service standards for space; and then fits them into an architectural concept.

The result is a design that will perform well (if none of the usual mistakes have been made) for a particular scenario. The problem is that neither the client nor the designer has any real idea how the design would perform under the wide range of circumstances that may well occur, and has no way to evaluate the performance of the proposed design with any other design.

Good design should do more than arrive at a feasible solution for a single scenario. It should define solutions that will perform well over the range of possible circumstances, and that can be demonstrated to be preferred to others. This is what we seek to achieve.

Proposed Design Process

An improved design process for passenger terminals would both address the specific analytic issues indicated above, and provide for the capability to assess the performance of any design over the range of circumstances it may encounter. This is what we propose.

Forecasting: Since the future traffic is so uncertain both as to level and its nature, what justification is there to postulate a single scenario at great effort ? The cost-effectiveness of this exercise must be close to zero since the cost is high and the value of the result about nil.

It makes more sense to concentrate professional effort in investigating the effects of the uncertainties. Thus the design effort should create a range of scenarios, with plausible ranges both for the levels of traffic and for key parameters that affect the design. It would, for example, want to consider a range of transfer rates, say from 25 to 75%, since these are known both to change and have a major effect on the design of a terminal (de Neufville and Rusconi-Clerici, 1978). Likewise, one could investigate the effect of changes in customs and security procedures, etc.

The values of the parameters and the levels of traffic would be nominated for each scenario. When the object is to define the performance of a system over a range of circumstances, it is not necessary to define whether any particular one is most likely. In nominating the values, only a rudimentary effort to justify them needs to be done. This approach thus scraps the very detailed, hour-by-hour speculations about what might happen a generation hence.

Specification of Level of Service Standards: This process would proceed as now, with two exceptions. It would focus attention on the matter of the dwell time, and it would also specifically investigate the possibility that concentrations of traffic at "hot spots" would degrade the overall performance of the terminal.

Dwell Times: ....Odoni section

Analysis of Traffic Concentrations: Traffic concentrations that degrade the performance of a terminal arise routinely. These "hot spots" then make the overall facility appear inadequate and, in effect, cause premature obsolescence or failure of the terminal. For example, the Air France terminal at Paris/Roissy had been intended to serve 10 aircraft operations per gate per day; however, because of the way passengers naturally tended to cluster around the check-in counters when these opened, thus blocking the passage of other passengers through the terminal, the number of daily operations per gate had to be reduced to about 6. The failure to anticipate this "hot spot", in a terminal for which there was largely enough area per occupant on average, forced the construction of a new terminal many years ahead of schedule (de Neufville and Grillot, 1982).

The analysis for traffic concentrations is quite simple. The key element is that the designers should put themselves in the shoes of the users of the terminal (Sommer, 1974). Patterns are then usually quite easy to detect, and avoid. People, for example, naturally cluster around information booths, the first queues in front of them, the mouth of the baggage chute, telephone banks, etc. These facilities should thus not be sited where they could cause bottlenecks. Most particularly, they should not be placed at the areas of maximum traffic in a corridor, as they so often are (!!!, see de Neufville and Grillot, l982), unless the design makes special provision for the presence of these facilities and their queues, as by widening the facility.

Flow Analysis: A computer model is virtually a necessity for exploring the performance of a complex system under a wide range of circumstances. But not just any kind of model will do. As a tool for the design of a system that should be evaluated for scenarios that can only be guessed at, the computer model of the flows should have three characteristics.

First, the model must be flexible. It must permit reconfiguration of the spaces, and thus the patterns of flows, without complex reprogramming. It must allow the design team to ask "what if" questions readily. In this aspect it should be rather like a modern "spread-sheet", which any reasonably computer literate professional can use.

Second, the model must be fast. It must be able to define the performance under all the combinations of conditions that might reasonbly arise, and this number rapidly becomes quite large. For example, if one wishes to consider the performance of the terminal for 3 levels of possible loads, with 3 possible transfer rates and, say 2 different possible customs and check-in routines, we have over a 100 possibilities to investigate -- for each design alternative!

Finally, however, the model need not be enormously precise. If we can only guess at the level of traffic to within 10% (and that would be good compared to the general record over a twenty year life of a terminal building), it is meaningless to try for greater detail in the analysis itself. The designer cannot hope, given the uncertainty of the traffic, to get a precisely accurate assessment of the performance of a terminal. The information that is useful will indicate the relative performance of alternate designs, and their ability to meet the range of possible loads. First or second place accuracy is all that is required.

This requirements argue for a new kind of "simulation" model for airport terminals, almost totally different from the simulation models of fifteen years ago. It would be flexible, not rigid; fast, not slow; aggregate not molecular. Fortunately, it would seem that programming and computer advances now make this possible.

The proposed "mini-simulation" models can be made flexible through the use of object-oriented programming (OOP), a programming style which modularizes classes of objects, and thus permits rapid redefinition. Speed is possible both through the improved hardware now available, and the smaller amount of data that needs to be handled once one recognizes that aggregate analyses suffice. Prototypes of these new "mini-simulation" models are in fact now available.

Conclusion

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