Airport Passenger Buildings:
Efficiency through Shared Use of Facilities

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Abstract

This paper provides a comprehensive guide to the design of shared facilities. Shared facilities serve many users (aircraft, airlines or types of services) in several functions (arrivals, departures, international and domestic, etc.). They significantly increase both the utilization of facilities, thus reducing the amount needed for any level of traffic; and the flexibility of the building, thus enabling it to accommodate easily variations in traffic composition (the fractions associated with specific airlines or international and domestic services). Shared facilities reduce capital expenditures by up to 30 percent, and correspondingly increase the return on the investment.

The design criteria for shared facilities depend on which factors primarily motivate their use. The main factors are peaking, that is variations in the levels of traffic (either in hours or a day), and uncertainly in the timing of the traffic (either in the short or long run). The paper details the appropriate analyses in each instance. This work implies that the design of passenger buildings should normally include shared space, swing gates and shared buffer facilities.

Key Words: Airports, Passenger Buildings, Terminals, Design, Shared Use, Multi-functionality, Flexibility, Peaking

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Introduction

Airport Passenger Buildings -- midfield concourses, finger piers or terminals -- now represent the major capital expenses at airports worldwide. This is because they are expensive, easily costing several hundred million dollars apiece at the largest airports (Suebsukcharoen, 2000), and because airports rarely get the opportunity to build new runways (as Table 1 illustrates).

[Table 1 about here]

Airport managers and designers are increasingly under pressure to be economically efficient. Most obviously, private companies have in many cases replaced the previous government agencies as owners and operators, and expect market rates of return on their investments. Companies such as the BAA (the owner/operator of the major British airports), the Airports Corporation of South Africa, the SEA (Societa Esercizi Aeroportuali, owner of the Milan airports), are setting the tone for financial efficiency, both at their own airports and through their investments and management contracts overseas (for example at Pittsburgh and Naples, Italy; in the Argentine and Australian airports; in the Athens/Spata airport, etc.). In parallel, corporatized public airports such as the Aéroports de Montréal, Vancouver and Aer Rianta (Ireland) actively run commercial investment and management services, in competition with private companies such as TBI/Airport Group International and National Express (UK). The bottom line is that economic efficiency is becoming a salient criterion for the design of airport passenger buildings.

Economic efficiency is a prime motive for the spread of shared-use, multifunctional facilities in airport buildings. Facilities that can be shared between several clients or users are a prime way to increase economic performance. They lead to greater rates of utilization and correspondingly lower costs per unit served than facilities designed to serve only one client or function. Multifunctional facilities, such as swing gates that can serve both international and domestic passengers, are thus becoming increasingly common internationally (see Table 2).

[Table 2 about here]

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These facts are leading to a new paradigm for the design of airport passenger buildings, featuring widespread use of shared multifunctional facilities. As stated in *Civil Engineering*:

> "The 1980s philosophy has been replaced by a new approach…by a philosophy more attuned to today's realities…of shared use of facilities… [This] has several impacts: terminals are being designed for incremental expansion, with the ability to expand quickly and efficiently as traffic growth dictates. Airports are striving to attain maximum efficiency from existing space…" (Reiss, 1995)

Obstacles to Shared-Use Design

Two main obstacles delay the widespread incorporation of shared-use, multifunctional facilities into the design of airport passenger buildings. One is tradition: typical practice has focussed on single-use facilities. The other is the lack of a comprehensive analytic approach to the design of multifunctional spaces.

Standard worldwide practice has favored single-use facilities. For example:

- Passenger waiting rooms typically (except in the United States) serve individual gates, as in the case in Amsterdam, Singapore and Taipei/Chiang Kai Shek;
- Terminals are normally dedicated either to Domestic or International operations -- thus at San Francisco/International, the airport in 2001 opened a new International Terminal distinct from the domestic operations;
- Facilities are typically dedicated to single airlines or groups, so it possible at Tokyo/Narita to speak of the Japan Airlines terminal, at Boston/Logan of the American, US Air or Delta terminals, at London/Heathrow of the British Airlines terminal, etc.

Single-use facilities have been locked into tradition for two mutually reinforcing reasons. First, airline passenger buildings were, historically, relatively inexpensive compared to runways and other major investments. There was thus practically no emphasis on cost analysis and cost reduction. Standard texts on airport design (Horonjeff et al, 1994; Ashford and Wright, 1992) do not discuss costs in relation to terminal design, and only mention the concept of shared-use in passing, if at all. Second, designers have not perceived much opportunity to reduce costs by sharing. The *Guidelines for Airport Terminal Facilities* of the US Federal Aviation Administration (FAA) tells them for example that:

> "When a lounge area serves more than one aircraft gate position, the estimated total lounge space … may be reduced by 5% for each aircraft position, up to a maximum of six gates." (US FAA, 1988, p. 79)

Such advice provides little incentive to pursue the design of shared-use facilities. Absent both motivation and tools, standard practice has thus not traditionally designed shared-used facilities.

The factors inhibiting the design of shared-use facilities are now out-of-date. Airport passenger buildings at large airports are expensive structures costing on the order of $10 million per gate (depending on what facilities are included in the calculation) and complete buildings cost hundreds of millions of dollars (depending on the size). Major airport buildings now also typically incorporate expensive automated systems for handling baggage and moving people. The need to pay close attention to these costs is inescapable. Moreover, it is becoming evident that shared-use, multi-functional facilities can offer far more significant cost reductions than suggested in 1988 by the FAA *Guidelines for Airport Terminal Facilities*.

The redesign of the terminal for the Second Bangkok International Airport (SBIA) illustrates the benefits to be achieved through shared-use spaces. In that case, the construction management team prepared a replacement design based on multifunctional facilities that reduced the number of gates by about 20% and the amount of space devoted to passenger hold rooms by about 35%, all while maintaining the same levels of service in the design. The overall cost savings for the complex was about XX%, based upon the prices bid in September 2000.

The improved cost reductions available from shared-use facilities derive from factors the previous guidelines did not anticipate. These are:

- Structural changes in the nature of commercial air transport associated with the economic deregulation of the airline industry; in particular the blurring of the distinctions between international and domestic operations, and the increased volatility of level and location of airline operations (see de Neufville and Barber, 1991, for example).
- Improvements in the analytic tools available to evaluate the economic efficiency associated with the use of multi-functional space. These tools demonstrate that shared space, because of its flexibility, has great value because it enables airport owners and managers to respond easily to significant variations in traffic levels without having to build more facilities. The most important specific advance lies in the application options analysis to design issues (see for example Trigeorgis, 1996; Amran and Kulatilaka, 1999).

The challenge at this stage is to articulate and implement a design philosophy consistent with current realities, that takes full advantage of the benefits of shared-use, multifunctional facilities for airport passenger buildings. The object of this paper is to present the range of concepts and analytic tools needed to execute efficient shared-use designs.

Previous Work

Several investigators have discussed specific types of shared-use facilities, and practitioners implemented them increasingly in the 1990's. This attention falls primarily into three categories:

- Waiting lounges in front of aircraft gates;
- Swing gates between international and domestic operations; and
- Gates at the airport.

Paullin (1966, 1969) is responsible for seminal work on shared use of passenger waiting areas in front of gates. He demonstrated that since passengers arrive gradually at the gates, and that aircraft normally leave the passenger building 10 to 15 minutes apart, the total space needed for N gates is less than N times the space needed for one gate. This is simply because the need for space for each is displaced in time, so that the total load is never the sum of the maximum amount for each individual gate. This is the analysis that backs up the previously cited *Guidelines for Airport Terminal Facilities* (US FAA, 1988).

Similarly, Wirasinghe and Shehata (1988) developed a formula for estimating the amount of space required for waiting lounges shared between N gates. Putting this on a comparable basis to the *Guidelines for Airport Terminal Facilities*, it is:

$$\text{Reduction in space due to sharing} = [0.5 - (1/3N)^{0.5}] \times 100\ \%$$

This works out to about 30% reduction in space when 6 gates share the lounge space. Their result compares well to the FAA recommendations of a 5% reduction per shared gate.

North American practice widely accepts the theoretical work on shared lounges. For many years they have been standard in the United States and in facilities built for US-based airlines (such as Terminal 1 at Tokyo/Narita and the American Airlines satellite at Terminal 2 for Paris/de Gaulle). Remarkably however, shared lounges are rare in airports elsewhere.

More important savings can be achieved by shared use than Paullin's approach indicates. Those analyses assume that the overlap between the aircraft departures is on the order of minutes, so that the traffic from one departure noticeably interacts with the traffic from the other. This factor limits the total benefits that can be achieved with shared use. Often however the time between flights is on the order of hours, and their traffic do not impinge on each other. This can occur at airports that serve intercontinental and domestic flights, whose peaks are far apart. For example:

- At Bangkok the intercontinental traffic peaks in the middle of the afternoon and around midnight, while the local traffic peaks in the early morning and evening;
- In New York, the European flights typically arrive in mid-afternoon and depart in the evening, while the local flights tend to peak around 9 in the morning and 5 in the afternoon; etc.

In principle, in such cases many of the gates needed for the peaks of intercontinental traffic could be completely used by local traffic in its peak, and vice versa.

In practice, shared use between domestic and international flights requires designers to build in the operational flexibility to take advantage of this possibility. They do this, for example, by designing corridors with a system of doors that can be locked and unlocked to permit flows through border controls or not, depending on the use. Airport designers have recently implemented a range of such facilities (see Table 2) achieving significant savings. At Mombasa, for example, the implementation of shared-use facilities lowered the total project cost for the airport passenger buildings by about a third (de Neufville,2000). The use of such facilities is becoming standard in Australia (Fordham, 1995), as this government pronouncement illustrates:

> "The integrated terminal facility will be purposely built for the current and emerging aviation environment wherein international, domestic and regional serves are closely integrated and airlines strive to make seamless transfers between domestic and regional services. The use of swing gates will further accentuate in face of the future in airport development as we move further away from the old order of rigid separation of the three levels of air travel." (South Australian Government, 1998)

The proposed new passenger buildings for Chicago/O'Hare for example will feature this kind of domestic/international shared use:

> "The renovation will include new federal inspection facilities in [the American and United] domestic terminals to give travelers a 'seamless transition from domestic to international terminals'…" (Associated Press, 2000)

The original analytic work on the sharing of gates at airports is due to Steuart (1974). He used queuing theory to estimate the number of gates a user (either an airline or an airport) requires to cope with both their peak scheduled loads, G, and their unscheduled extra needs due to delays and other random events, G*. A key implication of his work is that the fraction of extra gates needed in any situation, G*/G, decreases when the number of scheduled gates is larger. (Basically, this is because random effects tend to cancel out more when G is larger.) Bandara and Wirasinghe (1988, 1990) and Hassounah and Steuart (1993) carried out further work along these lines. Together their analyses formally justify the rule-of-thumb that airlines normally schedule gates for only up to 80% occupancy, knowing that they will need extra facilities to cope with random occurrences (Horonjeff and McKelvey, 1994).

A simple way to express the number of gates needed by any airline is (de Neufville, 1976):

$$\text{Total Gates Required} = G + G^* = G + (G)^{0.5}$$

This formula approximates the number of flights needing gates by a Poisson distribution and, by allowing a standard deviation extra (since in this case the standard deviation equals the square root of the mean), implies that over 95% of the aircraft would have immediate access to a gate.

The practical consequence of these results is that combining the requirements for individual airlines reduces the total needed. For example, if 3 airlines each have to provide for simultaneous peaks of 10 flights, they would each independently need about 13 (= 10 + √10) gates apiece or 39 in all. If the airport as a whole defined their joint requirements, it would establish the overall number of gates at around 36 (=30 + √30) -- which implies a savings of around 7%. If the airlines were smaller but collectively had the same demand for scheduled gates, the savings would be more impressive. Thus if 6 airlines each wanted 5 gates at the peak, the sum of their individual needs would be 45 (= 6[5 + √5]) gates and the savings achieved through joint use would be 20%. Gaudinat (1980) found similar results in looking at the needs of specific airports.

These kinds of analysis provide a rationale for the practice of centralized management of all the gates at an airport, which is standard in most of the world except the United States. (The United States is perhaps an exception because it features a handful of very large airlines, so the savings through common use of gates is less than at European or Asian airports which have many small airlines.) The same arguments applied to check-in facilities justify shared use of those counters, and thus the installation of CUTE (Common User TErminal) computer systems in these areas. According to Samuel Ingalls, the business manager of Las Vegas Airport in 1999:

> "I can't think of a single carrier that wouldn't say our [CUTE] system is an unqualified success. They have so much more operating flexibility. Carrier attitudes are changing." Especially when considering savings…. Ingalls says Las Vegas needed 10 to 15 fewer gates because of CUTE. (Feldman, 1999)

Overall, the review of the literature and practice on shared use facilities shows that current airport design covers the field unevenly and inadequately. What is widely recognized in some domain is virtually ignored elsewhere. Moreover, current practice misses important opportunities for the application of shared use facilities, as the next section indicates.

The questions airport designers need to address are:

- Under what circumstances are shared uses desirable?
- How should designers analyze these opportunities?
- What are practical results?

The rest of the paper addresses these issues.

Drivers for Shared Use

Two factors appear to be the primary drivers that motivate the use of shared space:

- Peaking of traffic at different times; and
- Uncertainty in the level or type of traffic.

The time period over which these drivers take place also influences their form and consequence, as Table 3 indicates. Moreover, as Table 4 suggests, each combination of driver and time period requires a distinct form of analysis.

[Tables 3 and 4 about here]

Peaking of Traffic: When distinct parts of the traffic peak at different times, shared use of facilities is economical. This is simply because the facility required for the peak of one kind of operation can be used for other operations as the peak of the former abates and is replaced by peak traffic of the latter. The sharing reduces the size or number of facilities that the airport needs to provide for a given total traffic, and thus increases their productivity and the return on the investment.

This driver of shared use has nothing to do with uncertainty. It would operate even if the flows of traffic were absolutely known. The observation is important because it underlines that the analyses appropriate to this peaking factor, and the resulting consequences, are quite different from those associated with uncertainty.

To make it possible to share facilities between operations that peak at different times, airport operators must be able to "swing" the use of the facility from one use to another. Designers make this possible by building in the features necessary to implement such swings in use. For example, to enable shared lounge space, they have to create "swing space", that is, joint lounges that can be used for several gates instead of individual gate lounges separated from each other by walls or other barriers. To permit sharing of departure gates, designers have to build corridors that connect these gates with the appropriate users. Specifically, when regulations require these users to be segregated (as typical for international and domestic operations), designers must provide corridors through a system of doors that can be securely and reliably opened and closed as needed.

The time between the distinct peaks of traffic influences both the types of analyses and the design of the shared facilities. Two types of intervals appear salient with respect to peaking:

- Very Short, where the peaks occur in the range of about an hour, as for example in the case of passengers waiting to board aircraft leaving 10 to 20 minutes apart; and

- Short, where the peaks occur at widely separate times of day, as for the peaks of international and domestic traffic at many airports.

When the interval between different peaks is very short, two dependent consequences arise. First, the traffic flows associated with the different peaks interact noticeably and, secondly, it is impractical to separate these flows easily. The interaction means that the advantage of sharing the facilities is only a fraction of the total, as indicated for example in the FAA Guidelines cited earlier (US FAA, 1988). It also implies that mechanisms requiring substantial operator intervention, such as the opening and closing of secure doors, are difficult to implement.

When the interval between peaks is on the order of several hours however, it is possible to dedicate a facility totally to an alternative use, as when a "swing gate" serves international traffic during its peak, and domestic traffic at another time. Alternatively, airlines can also "swing" the designation of an aircraft from a domestic arrival to an international departure (as when a flight arrives at Chicago/O'Hare from St.Louis and proceeds on to Frankfurt, Germany) and thereby avoid the cost and delay of towing the plane across the airfield. Over longer periods it is also possible for the airport operator to make the effort required to create alternative secure paths to the gate, as required when domestic and international traffic must be separated.

<u>Uncertainty</u>: Uncertainty in the levels of traffic is the other principal driver motivating shared use. The issues in this case are that:

- Additional facilities are required to "buffer" the system against either peaks greater than the scheduled peaks that could happen through delays and other events or uncertainties in long term requirements;
- The efficient size of the buffer depends on either the frequency of the peaks or the range of the uncertainty in the long term needs; and thus
- It is economical to provide these "buffers" jointly for several users, rather than individually for each user.

The economy from shared use of the buffer facilities arises because the peak needs for the entire system are normally considerably less than the sum of the possible peaks for each element of the system. In the shorter term this is because stochastic flows for some users frequently compensate the peaks of other users. While this fact may not reduce the maximum possible peak, such as might occur when all users suffer delays during a major storm, it does reduce the frequency of peak loads. Since the economically efficient size of the buffer represents a tradeoff between the cost of the buffer and the cost or inconvenience of not having extra space when it is needed, anything that reduces the frequency of need leads to a reduction in the desirable size of the buffer space. In the long term, the actual total requirements for a specified level of total traffic is less than the sum of the anticipated possible maxima for individual uses, since some uses do not meet the possible levels.

To enable the economies of shared buffer space, designers should place this capacity between the core facilities of major users, so that they can easily use it when needed. This implies that the airport passenger buildings should somehow be connected rather than independent, as they are in a "unit terminal" configuration. At Singapore, for example, all the buildings are connected, so that it is easy in principle for one airline to use additional gates when its neighbor does not require them. On the other hand, at Chicago/O'Hare or at Baltimore/Washington it has proven impractical to allocate gates at the separate International Terminals to domestic services, a fact that has caused substantial operational and financial problems. (In each case, the "buffer" of extra international gates provided in anticipation of uncertain future requirements could not be used when the relative share of traffic of international traffic dropped. In Chicago this was because international airlines could depart for international destinations from domestic gates once they joined the alliances; in Baltimore because US Airways moved its much of its international traffic to Philadelphia while Southwest Airlines grew domestic traffic rapidly. (Little, 1998; Baltimore-Washington International Airport, 1988)

The timing of the uncertainty influences both the types of analyses and the design of the shared facilities, as it does for the peaking factor. Two types of interval appear meaningful with respect to uncertainty:

- Short, where the uncertainty arises from operational factors such as mechanical and weather delays, and is resolved over one or two days; and
- Long Run, where the uncertainty is about the level of future operations for different users, and may only be resolved over years.

When the uncertainty is resolved over days, the analysis is conceptually simple. Its essence lies in a tradeoff between the cost of the additional facilities and the costs associated with delays and schedule disruptions that arise when facilities are not available when needed. Exact calculations of these tradeoffs are impossible in practice since airport designers have no credible basis for estimating the costs of disrupted schedules for airlines years in the future. Exact calculations are unnecessary however since the base requirements at any airport constantly change with the level of traffic, and thus so does the size of the remaining "buffer" capacity. In this circumstance, the analyses and rules of thumb cited in the previous section seem adequate.

The analysis is more complex when the uncertainty covers several years. This is because the cost of constructing flexible "buffer" facilities now must be traded off against benefits far enough in the future that they should be discounted. Furthermore, when dealing with uncertainty the appropriate discount rate should be adjusted for risk through Capital Assets Pricing Model procedures (see for example Brealey and Myers, 1996). To assess the value of the flexibility provided by the "buffer" space to meet future demands, what needs to be done or approximated is a "real options" analysis (Amram and Kulatilaka, 1999; Trigeorgis, 1996) as indicated in the next section.

Analysis Methods

Four major cases need to be considered, defined by the shorter and longer periods for each of the two drivers of shared use. In three out of four of these cases, this paper presents new or updated approaches. For completeness however, it presents each of the major practical approaches to defining how much shared space should be designed into an airport passenger building, under what circumstances.

<u>Peaking, Hourly Variation</u>: The classic example of this situation is the sharing of gate waiting areas. Other facilities, such as check-in counters, baggage handling and screening devices and VIP lounges can be analyzed similarly.

A spreadsheet simulation is the most versatile and cost-effective way to analyze these situations. Spreadsheets easily handle the basic calculations, which consist of adding up the passenger arrivals for several flights and subtracting the departures. The entries in each cell giving the traffic arriving or departing for each flight can be defined parametrically in terms of the size of the aircraft, its load factor, the time when passengers arrive and start boarding, and the pattern of these flows over time. All kinds of combinations can then be explored automatically by means of the "data table" function that is the basic feature of spreadsheet programs. Designers can easily construct such a model for any situation in about a day, if necessary using Belin (2000) as a model. This approach is identical in spirit to that defined by Paullin (1966), but is far more general because it lets designers examine the consequences of different sizes of aircraft, times between departures, boarding policies, etc.

Table 5 presents typical spreadsheet results for the calculation of the space savings achieved by shared use of lounges. The space needed depends mostly on the time between departures since this is the factor that permits a preceding flight to empty space thus making room for passengers for the later flight. Notice that in a spreadsheet analysis, the time between departures does not have to be spread evenly over an hour as assumed for simplicity in purely mathematical analyses

(Paullin, 196; Wirasinghe and Shehata, 1988). Most importantly, observe that space sharing can cut requirements in half under some assumptions, and in any case generally far more than the 1988 FAA Guidelines assume.

[Table 5 about here]

The space needed also depends on the number of flights sharing the lounge. The effect diminishes as the number of gates increases. As Figure 1 indicates graphically, combining more than 6 gates leads to practically no additional improvement in any case. Experienced designers recognize this fact, and usually plan on having about 4 gates share lounge space.

[Figure 1 about here]

Figures 2 and 3 show the results for a combination of cases (different size of aircraft, load factor, minutes available for boarding, minutes between aircraft departures, minutes before departures that first passengers arrive at the gate). These figures illustrate the kind of results that are easily available from the spreadsheet analysis, and thus demonstrate how this approach can be tailored to the needs of specific situations. Overall, the figures demonstrate that shared use of space can lead to far greater savings than suggested by the 1988 FAA Guidelines.

[Figures 2 and 3 about here]

<u>Peaking, Daily (or longer) Variation</u>: A prime example of this situation is the use of gates. Different airlines or services will often exhibit distinct patterns of peaks over a day. Short-haul airlines serving business traffic, either domestically as in the United States or internationally as between Singapore and Kuala Lumpur, may have traffic peaks in the morning and evening. Trans- or intercontinental services on the other hand, may have peaks determined by time zones, as when European flights arrive in New York in the early afternoon and leave late in the evening. The distinct peaks can thus occur in the same passenger building, as between airlines in an alliance. They may however be most significant between international and domestic terminals.

The opportunity for sharing arises when peaks of different users do not overlap because one user can use a block of facilities when others do not need them. They can share gates most obviously, but also all the supporting facilities such as check-in counters and baggage services. In Boston, for example, American Airlines is planning to build a new international/domestic passenger building. It will have 2 gates and Federal Inspection Services to serve international traffic, but will also cater to domestic flights when there are no international arrivals.

A spreadsheet program is the most versatile and easy way to analyze the possibilities of sharing in these cases also. A simple way to do this involves creating a table of the requirements for gates by time of day and type of use (airline, aircraft, type of service, etc.). Designers can obtain the total number needed for each category separately, or for categories merged in various ways, thus easily testing different forms of sharing. They can display the results in the Gantt charts that airlines normally use to plan and display their gate assignment schedules, as shown in the top portions of Figures 4 and 5. These often effectively communicate the advantages of sharing to an audience of non-experts, such as a board of directors.

[Figures 4 and 5 about here]

When peaks of different users are hours apart, it is not practical to give general guidelines for the reduction of the amount of facilities possible through sharing. This is because the flows of aircraft to various airports are not so universally regular as flows of passengers to aircraft. It is however possible to assert on the basis of examples that the savings may be considerable. At Mombasa Kenya), for example, the tourist flights from Europe arrive at daybreak and leave around mid-night, so that they are almost totally out of phase with the domestic flights from Nairobi that operate during the day. When the Kenyan Government built a new terminal in the 1990s, it was thus almost possible to share facilities totally and halve the number of gates required (de Neufville, 2000).

<u>Uncertainty, Daily Variation</u>: This uncertainly occurs routinely due to weather and mechanical delays. These stochastic delays drive the airlines to request additional gates and back-up facilities beyond their scheduled peak needs. They want this flexibility so that they can service their flights when late or delayed aircraft block gates scheduled for other users.

As a practical matter, extensive analysis beyond the available formulas (de Neufville, 1976; Bandara and Wirasinghe 1988, 1990; Hassounah and Steuart, 1993) is not useful. This is because a correct analysis would require information that is too speculative and unreliable. A full analysis for any airport would estimate the future probabilistic distribution of weather and mechanical delays, and balance it with the cost of additional gates and the value of the flexibility to the airlines in terms of both out-of-pocket and opportunity costs.

The existing formulas teach designers what they need to know. Designers can reduce the number of gates by about 10 to 15% by incorporating shared gates among airlines, particularly among smaller airlines. They must however balance this opportunity against both the management costs and passenger confusion associated with varying gate assignments. A convenient design solution may be to place the extra facilities needed for stochastic delays between major blocks of airlines or airline groups. They can then be available as occasionally needed, without requiring constant management of all the gates.

Uncertainty, Long Term Variation: The issue here is that the mix of traffic at an airport varies over the years, so that designers run the risk of getting the proportions wrong. The future proportion of traffic represented by international traffic, by an airline, by a type of aircraft (e.g. narrow or wide body) is almost certainly not what it is, or is forecasted to be, at the time of design. To the extent that airport traffic grows at about 5 to 7% annually, and that airport owners build major new facilities every decade or so, designers normally plan facilities about twice as big as needed immediately. In doing so, they have to make decisions about the proportion of facilities to create for each class of user, at a time when these are uncertain.

The uncertainty in the mix of traffic motivates flexible design, specifically shared use, which can be allocated to the users who will need it in the future. In this context, shared use facilities provide some insurance that the appropriate facilities will be available when needed. Airports that fail to provide this kind of insurance may end up with considerable wasted space and resources. The 1990s experience of Baltimore illustrates this phenomenon. In that case the airport built a major international terminal principally for US Airways. Unfortunately for the airport, however, US Airways moved much of its foreign traffic to Philadelphia. Meanwhile, Southwest Airlines was growing rapidly, and required more space. The rational thing to have done was to let Southwest use the gates left vacant by US Airways. Unfortunately for the airport owners, however, they had failed to provide flexible space, could not use their existing facilities to capacity and thus wastefully had to build new facilities (Baltimore-Washington International Airport, 1998; Little, 1998; Belin, 2000).

The provision of facilities that can be used for one purpose or another is known technically as a "real option" (Trigeorgis, 1996; Amran and Kulatilaka, 1999). Speaking technically, an "option" has a precise meaning going beyond the ordinary connotation of "choice". Formally, an option represents the capability of doing something at the owner's discretion, without being under the obligation to do so. In finance, an option is a contract to buy or sell something (a 'put' or a 'call' for example). In design, a "real" option represents a tangible capability to initiate some action. Flexible space is an option because it provides the ability (but not the obligation) to use a facility in an alternative use sometime in the future. As an option, it has been acquired at some expense, that is the cost of equipping the facility to serve a multifunctional use. The option is "real" because it consists of physical facilities instead of the contractual arrangements that characterize financial options (see Brealey and Myers, 1996).

Options analysis provides the mechanisms to calculate the value of flexibility, and thus to decide how much to acquire. When applied to real options, it permits designers to calculate the value of flexible physical arrangements (such as shared space) and to determine how much to include in the design. Options analysis, when fully implemented, has the great merit of making it possible to apply a consistent risk-adjusted discount rate to the future investments and costs, in the context of varying risk. It is a break-through that is radically changing the way professionals can (and should) evaluate major projects, and was the subject of the Nobel Prize for Economics in 1998.

For airport planning, the best approach is to use decision analysis to approximate options analysis. This is because designers will have neither the historical data to justify detailed probability assessments of future mixes of traffic, nor any way to specify the costs of insufficient capacity accurately. Decision analysis provides a compromise approach to assessing the value of real options. It provides the essential rigorous analysis comparing possible levels of investment in shared use facilities, with the prospective expected value of these investments over the scenario of future outcomes (Faulkner, 1996).

The decision analysis to determine the appropriate amount of shared space to insure against uncertainty about future traffic proceeds along conventional lines (see for example de Neufville, 1990). The root choices are the levels of swing capacity, and the subsequent chance nodes reflect the mix of capacity actually needed at the end of the planning period. The outcomes sum the extra cost of providing the swing capacity (in terms of sterile corridors and other necessary mechanisms) and the cost of meeting any shortfall in the capacity required for any particular use. Figure 6, illustrates the structure of the analysis. It represents an analysis for Phase 1 of the Second Bangkok International Airport, for which the designers projected a planned capacity of 30 Million Annual Passengers (MAP), but thought the international traffic (A) might need anywhere from 21 to 25 MAP, and the domestic traffic (B) from 5 to 9 MAP. As can be imagined, the rational design does not provide for the sum of the maximum possible for each use, 34 MAP (= 25 + 9), but for a lesser amount consisting of dedicated gates and multifunctional gates that can be shared or eventually dedicated to one use or the other.

[Figure 6 about here]

In the case of airport planning, the decision analysis should deal with two scenarios: normal and extraordinary variability in mix. Normal variability refers to the routine variation around trends in mix of traffic that can be observed at an airport. For example, as the proportion of international traffic at San Francisco moved from 11 to 18% or that of Bangkok from 80 to 71% in the 1990s several fluctuations occurred around the trend (ICAO, 1990-97). Extraordinary variability occurs when major shifts in the mix of traffic occur, for example when United Airlines unexpected built up a hub operation at Washington/Dulles, or when US Airways pulled much of its international traffic out of Baltimore. Extraordinary variability implies a much greater range of risk and thus of shared facilities. Furthermore, each scenario implies a different probability distribution of outcomes.

Normal variability is derived from historical records. For example, consider an airport with two types of traffic, A and B, which could be international and domestic say. Airport data over the years will allow the designer to calculate the:

- share of traffic, A/(A+B);
- statistical trend using regression; and
- standard deviation around the trend: $s = [\Sigma_n (\text{actual traffic in a year - trend traffic})^2 /(n-1)]^{0.5}$

Assuming a normal distribution of outcomes, these data permit an extrapolation to the end of the planning period of both the modal expected mix and the range.

Extraordinary variability is speculative. Its probability and maximum shift (in terms of percentage of the mix) can only be derived from judgement. For example, a congested airport such as Boston can reasonably be assumed to have little future as a transfer hub. Orlando/International however, an airport with large capacity and convenient runways, might become a transfer hub at the expense of Miami that runs the possible risk of losing some of that status. The fact that this risk is subjective however cannot deny either its importance or the responsibility of good designers to provide some appropriate level of flexibility for dealing with these real risks.

Doing the decision analyses for the normal and extraordinary variability parametrically leads to some useful results. Belin (2000) ran the analyses for a wide range of relative extra cost of swing gates (beyond the cost of single function gates), of risk and, of the range of possible shift in mix for the case of extraordinary variability. Figures 7 and 8 illustrate the resulting guidelines.

To provide insurance against normal variability, Figure 7 indicates that the percent of shared use gates should be on the order of the standard deviation around historical trends, so long as the additional relative costs of implementing swing gates is not too high. This makes sense intuitively. One standard deviation covers the bulk of the distribution of the risk, and it is natural that designers should provide less insurance as the risk diminishes. As a general guide for conceptual planning, Figure 7 seems reasonable.

[Figures 7 and 8 about here]

To provide insurance against extraordinary variability, Figure 8 indicates that the desirable percent of shared gates depends both on the absolute size of the possible shift, and the probability this may occur. As for normal variability, the upper limit on the percent corresponds approximately to the size of the possible shift. In addition, the desirable percent of shared gates decreases as the probability of the shift is rarer. It also decreases as the cost of the shared gates increases, as the comparison of Figure 8 and 9 Illustrates.

[Figures 8 and 9 about here]

Practical Implications

From a design perspective, the salient implication of traffic peaks occurring at different times and of uncertainty in demand, is that shared use facilities should be widely integrated into airport passenger buildings and their supporting facilities. In detail:

- As regards lounge space the evidence is that planners should routinely design for about 4 gates to share the same waiting room.
- The guidance is less clear for gate sharing to the extent that the costs of implementing multifunctional gates are substantial (due to the need to accommodate different types of aircraft, or both international and domestic flights). Nonetheless it appears that at least 20 to 30% of the gates at an airport might best be designed for shared use, considering the combined effects of providing both for daily uncertainties and normal long-term variability.

From an analytic perspective, the task appears quite simple. The number of shared facilities can be determined within the limits of practical significance by simple methods, spreadsheets, formulas or the results of parametric calculations. In detail:

- Speadsheets are good for calculating the size of the lounges and the possibilities of sharing between users at different times of day;
- Existing results of parametric calculations (as in Table 1, Figures 1- 3 and 7 - 9) can be used for determining the size of gate lounges and the percent of extra gates due to long-term variability in the mix of traffic; and
- Formulas can also be used for calculating the size of lounges (although the Guidelines of the FAA (1988) appear conservative) and the percent of extra gates needed to cope with short-term uncertainty due to weather and mechanical delays.

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Table 1: Preponderance of Current Capital Investments in Airport Passenger Buildings in North America as of 2000

City / Airport	Major Buildings	Major Runways
Atlanta	Yes	Plan
Boston/Logan	Yes	
Chicago/O'Hare	Yes	
Dallas/Fort Worth	Yes	Yes
Denver	Yes	Yes
Miami/International	Yes	Plan
Montreal/Dorval	Yes	
New York/Kennedy	Yes	
New York/LaGuardia	Yes	
Orlando/International	Yes	
Philadelphia	Yes	
Pittsburgh	Yes	Yes
San Francisco/International	Yes	Plan
Saint Louis	Yes	Plan
Seattle		Yes
Washington/Baltimore	Yes	
Washington/Dulles	Plan	

Table 2: Examples of Airports with International/Domestic Swing Gates

Region	City	Airport	Installed	Planned
North America	Atlanta	Hartsfield	1994	
	Boston	Logan		Plan
	Calgary	International		2004
	Chicago	O'Hare		Plan
	Dallas/Fort Worth		1993	
	Denver	International	1995	
	Fort Myers		1993	
	Las Vegas	McCarran	1991	
	Los Angeles	International	1985	
	Miami	International		
	Montreal	Dorval		2002
	Orlando	International		2004?
	Orlando	Sanford	2000	
	Toronto	Pearson	yes	2002?
Australia	Adelaide			2001
	Brisbane			Plan
	Cairns			Plan
	Darwin			Plan
	Hobart			Plan
	Perth			Plan
New Zealand	Christchurch			Plan
	Wellington			1999
Asia	Bangkok	Nong Ngu Hao		2004?
	Kuala Lumpur	Sepang		1998
	Osaka	Kansai		1994
	Nagoya	Chubu		Plan
Africa	Cairo		1998?	
	Mombasa		1995	
Europe	Birmingham		1990	

Source: Belin (2000)

Table 3: Primary and Secondary Drivers Motivating the Use of Shared Use, Multifunctional Facilities

Drivers		**Examples**
Primary	Time Factor	
Peaking At different times	Very Short (hours)	Swing space: sharing gate lounges between flights
	Short (over day)	Swing gates for international/ Domestic flights
Uncertainty in type of traffic	Short (daily)	Additional gates to handle extra peaks for weather, etc
	Long Run (years)	Reserve swing gates to cope with uncertain future growth

Table 4: Analysis Methods Recommended for dealing with each factor motivating the use of Shared, Multifunctional Facilities

Drivers		**Analysis Methods**	**References For each Method**
Primary	Time Factor		
Peaking At different times	Very Short (hours)	**Simulation** specific to site or **Available Tables**	Paullin (1966) etc. US FAA (1988), Belin (2000)
	Short (over day)	**Analysis of Operations** (Site Specific)	Belin (2000)
Uncertainty in type of traffic	Short (daily)	**General Formula** or **Stochastic Analysis**	de Neufville (1976) Steuart (1974), etc.
	Long Run (years)	**Real Option Analysis** or **Decision Analysis**	de Neufville and Belin (2002) Belin (2000)

Table 5: Space Needed for A Waiting Lounge Shared by N Gates, as a Percent of the Space Required by the Sum of N Individual Lounges (200 passenger aircraft, 60 minutes occupancy at gate, various times between departure).

Time Between Departures (min)

Number of Flights Sharing Lounge	0	3	6	9	12	15
2	100	94	87	81	75	70
3	100	87	75	64	56	49
4	100	81	63	51	42	37
5	100	76	54	41	34	
6	100	72	48	34		
7	100	67	42			
8	100	63	37			

Figure 1: Space Needed for a Waiting Lounge Shared by N Gates, as a Percent of the Space Required by the Sum of N Individual Lounges (200 passenger aircraft, 60 minutes occupancy at gate, various times between departure).

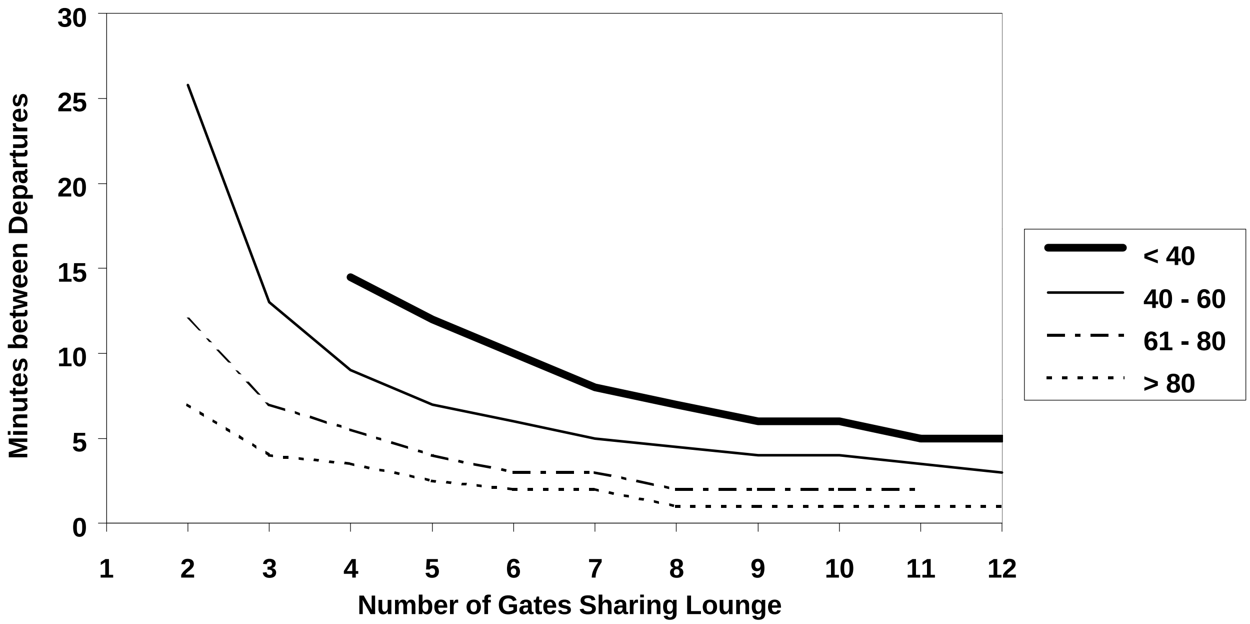

Figure 2: Space Needed for a Waiting Lounge Shared by N Gates, as a Percent of the Space for an Individual Lounge (200 passenger aircraft, 80% Load Factor, Boarding starting 20 minutes before departure, for various scenarios for time when first passengers arrive and between departures.

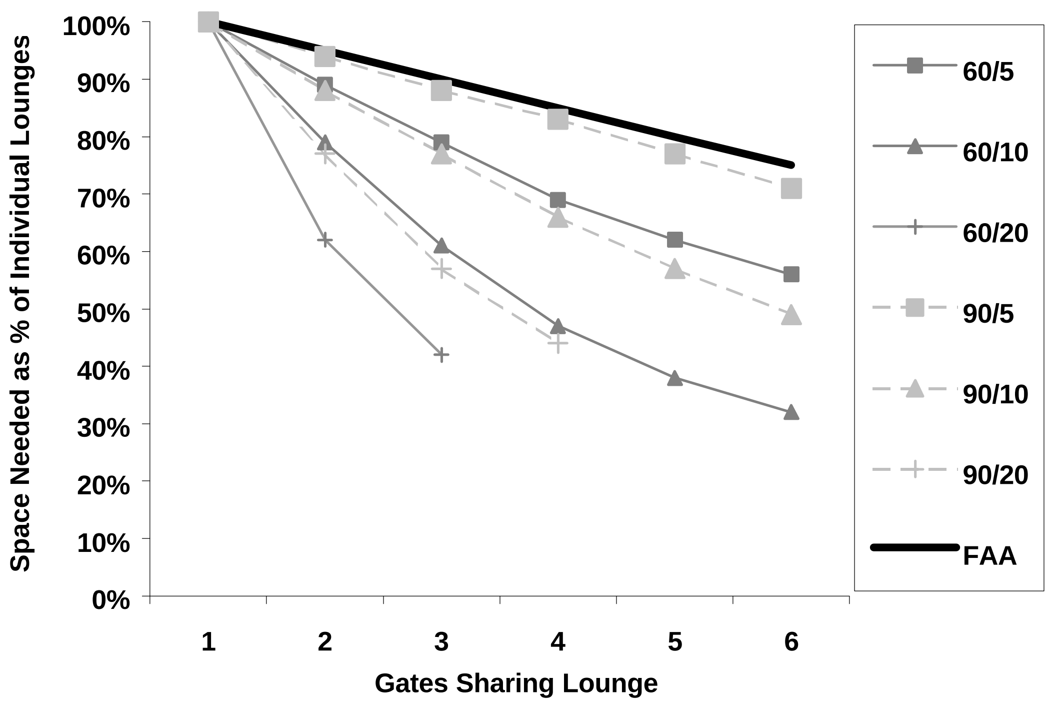

Figure 3: Space Needed for a Waiting Lounge Shared by N Gates, as a Percent of the Space for an Individual Lounge (420 passenger aircraft, 80% Load Factor, Boarding starting 30 minutes before departure, for various scenarios for time when first passengers arrive and between departures.

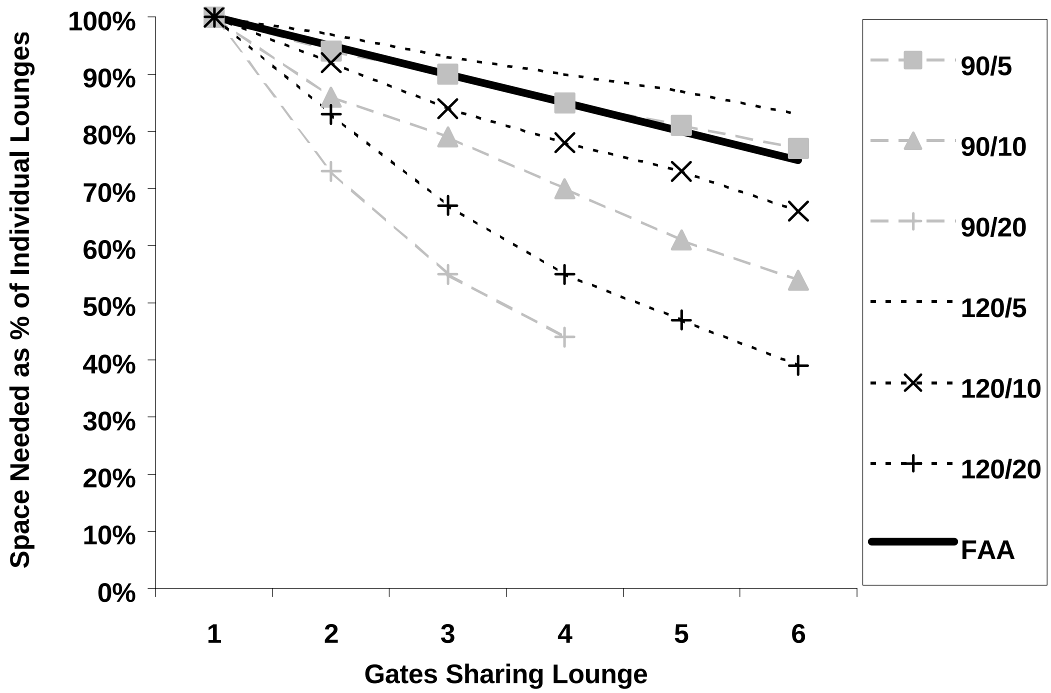

Figure 4: Gantt Chart for Example Use of Gate Positions by Two Distinct Users, with no Sharing of Facilities.

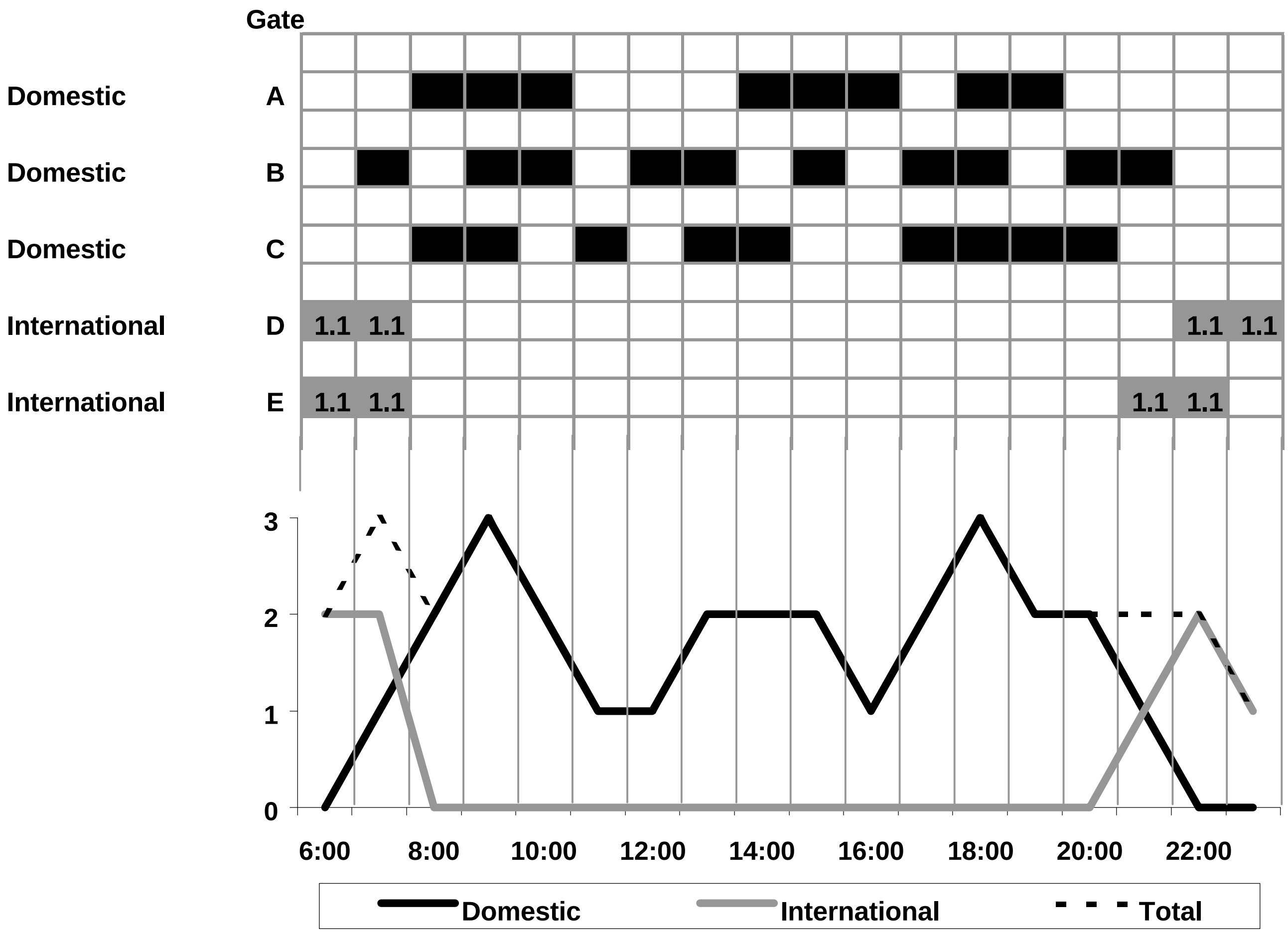

Figure 5: Gantt Chart for Example Use of Gate Positions by Two Distinct Users Sharing of Facilities, showing the Possible Reduction in the Total Number of Gates Needed.

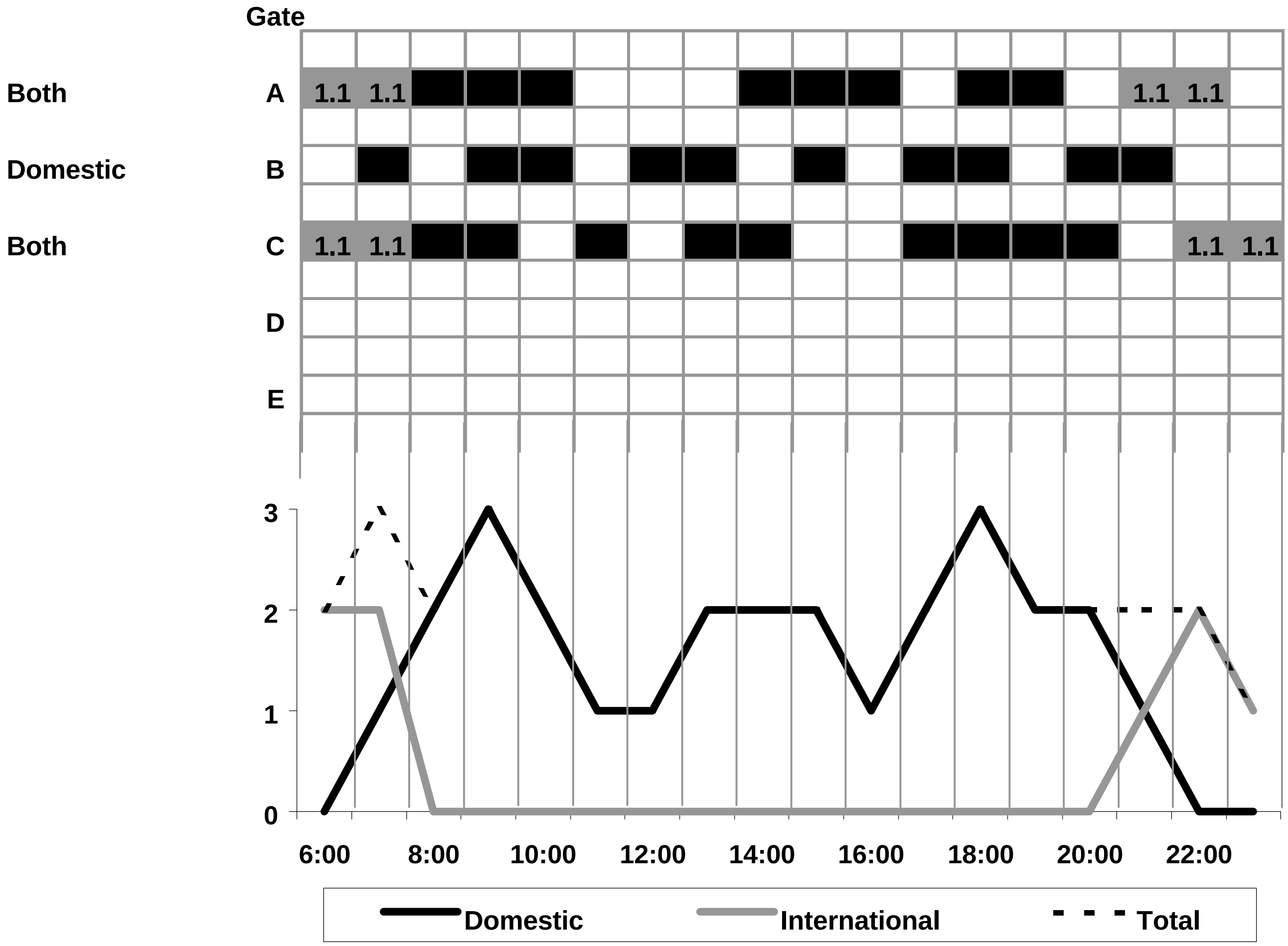

Figure 6: Example Structure of the Decision Analysis for determining the Gate Capacity to Provide Insurance against Variability in the Mix of Traffic

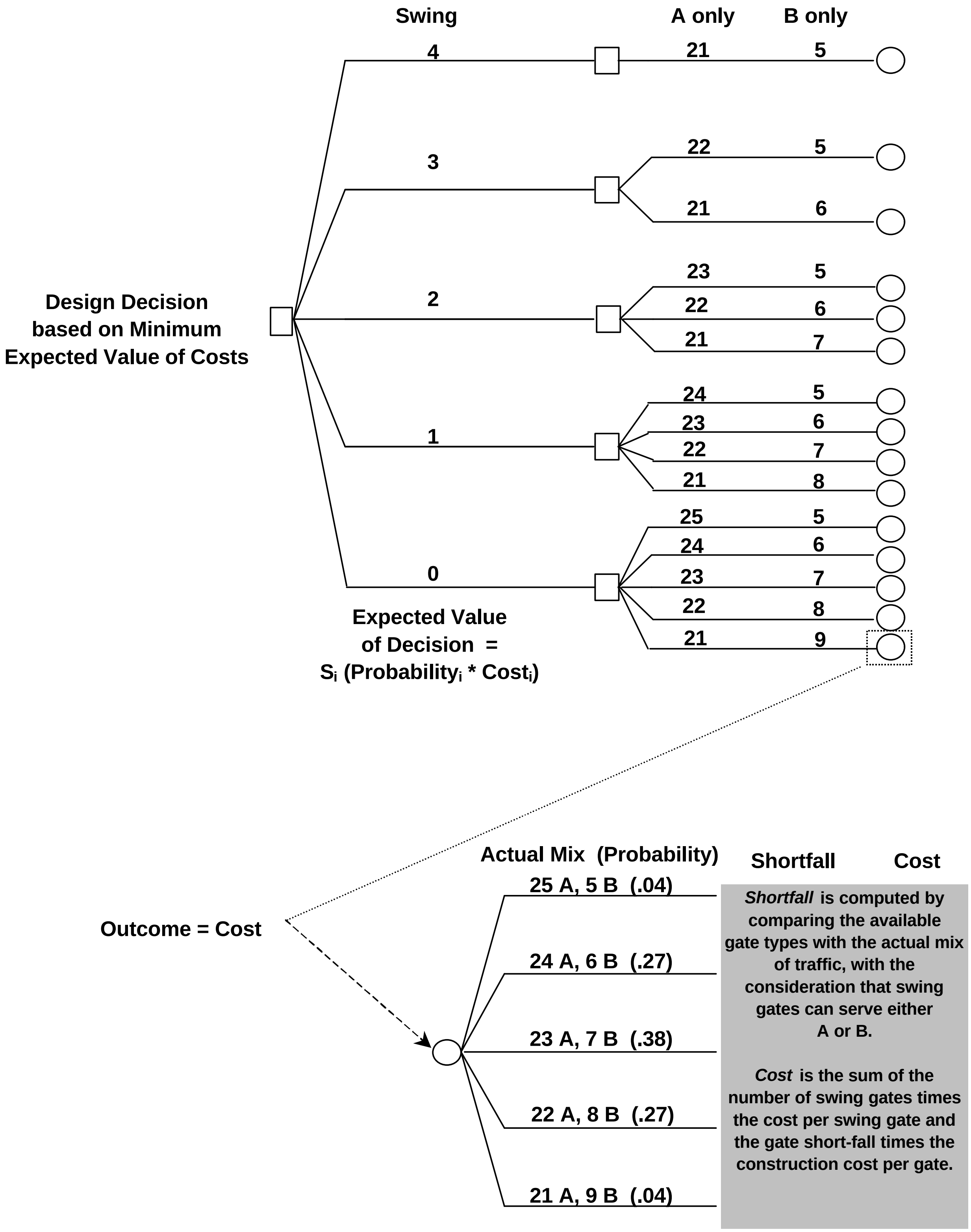

Figure 7: Proportion of Swing Gates to Provide to Insure against Normal Variability

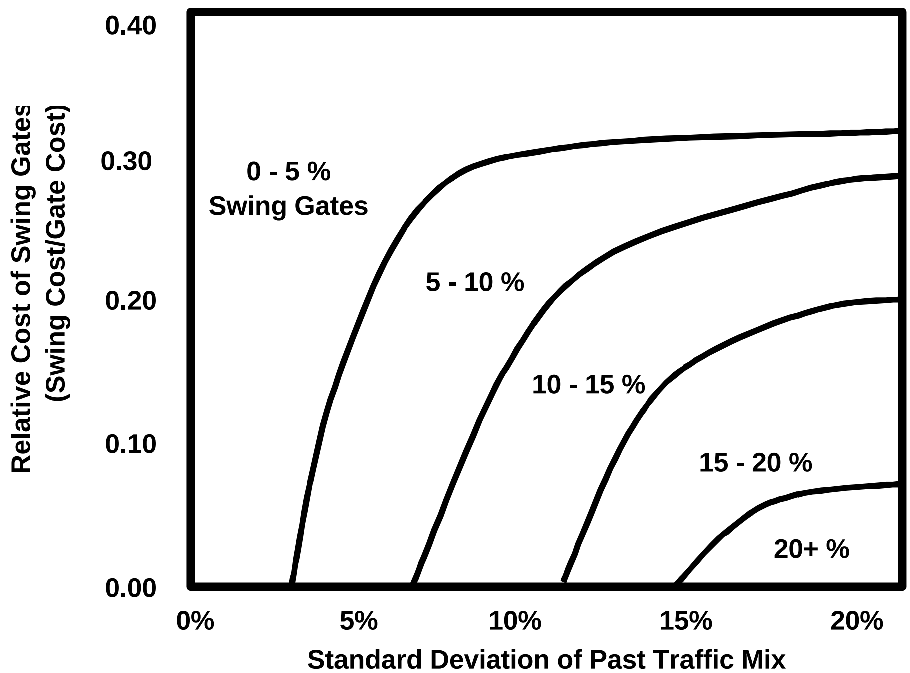

Figure 8: Proportion of Swing Gates to Provide to Insure against Extraordinary Variability, when Swing Gates cost 20% more than Normal Gates

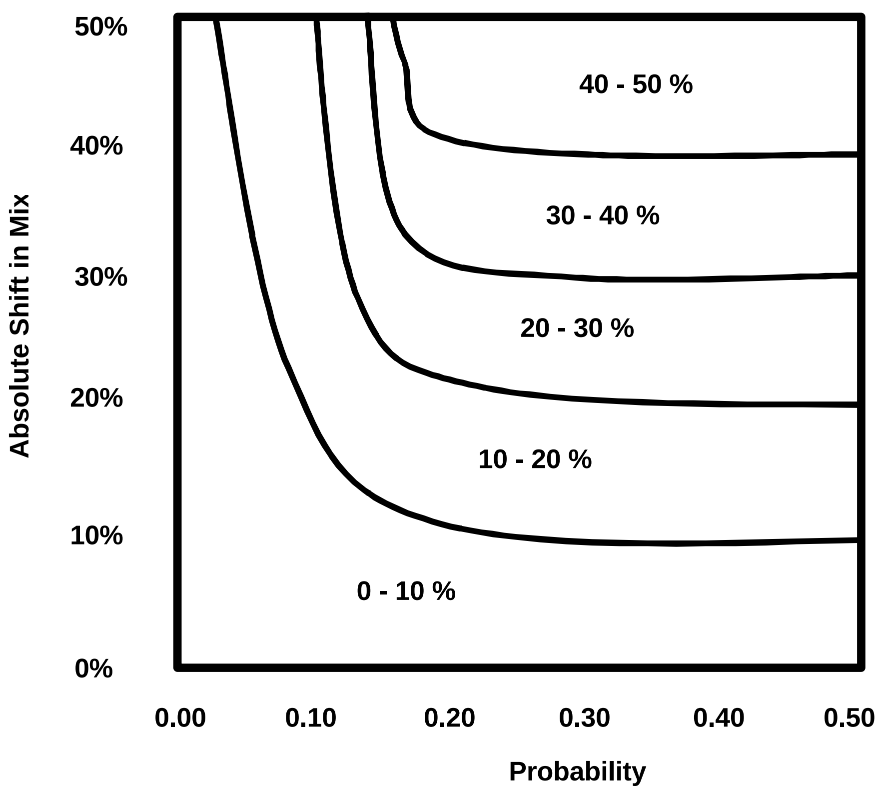

Figure 9: Proportion of Swing Gates to Provide to Insure against Extraordinary Variability, when Swing Gates cost 5% more than Normal Gates