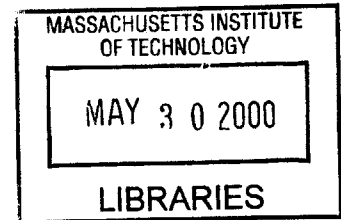


**Designing Flexibility into Airport Passenger Buildings:
The Benefits of Multifunctional Space and Facilities**

by

Steven C. Belin

S.B. Civil Engineering
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ENG

Submitted to the Department of Civil and Environmental Engineering
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Master of Science in Transportation

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Signature of Author
Department of Civil and Environmental Engineering
May 10, 2000

Certified by
Richard de Neufville
Professor of Civil and Environmental Engineering and Engineering Systems
Thesis Supervisor

Accepted by
Daniele Veneziano
Chairman, Departmental Committee on Graduate Studies

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ABSTRACT

Airport passenger buildings will be cost-effective if their design allows for flexibility in the provision and allocation of capacity. This thesis provides a typology of situations in which flexibility is needed conceptually, a methodology to estimate the value of this flexibility, and examples of flexible designs that have been implemented in practice. It is the first comprehensive guidance for determining how much flexibility should be provided in airport passenger buildings.

The need for flexibility is driven by peaking and uncertainty in current and future demand. Flexibility comes in different forms depending on the time frame and the nature of the demand. In the context of airport passenger buildings, spare capacity, expandability, and multifunctionality are the most important forms of flexibility. Spare capacity and expandability are commonly provided and have been analyzed extensively.

Multifunctionality, however, has not been explored in detail and is thus the focus here. Multifunctional facilities can (1) be shared between different users if their peaks do not coincide, reducing capital and operating costs; and (2) can easily adapt to changing conditions, providing insurance against the risk of obsolescence when future traffic and operations are uncertain.

Spreadsheet-based operational models and decision analysis are used to estimate the value of this flexibility. These benefits are traded off with the upfront cost of building in the flexibility to provide guidance on the optimal amount of flexibility. Appendices provide documented examples of shared departure lounges and international / domestic swing gates currently in use or planned at airports worldwide, emphasizing the benefits of multifunctionality.

Thesis Supervisor: Richard de Neufville

Title: Professor of Civil and Environmental Engineering and Engineering Systems

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Chapter 1. Introduction: Flexible Planning and Design of Airport Passenger Buildings

Flexibility is widely accepted to be an important feature of airport passenger buildings. This thesis offers a comprehensive analysis of designing passenger buildings to be cost-effective through the flexible provision and allocation of capacity. It provides a typology of situations in which flexibility is needed conceptually, a methodology to estimate the value of this flexibility, and examples of flexible designs that have been implemented in practice. In addition to the accepted practice of designing buildings to be expandable, space and facilities should be designed for multifunctionality. Multifunctional facilities provide flexibility in both current operations and long term development.

Airports of all sizes around the world have to expand and renovate existing passenger buildings and build new ones in response to the growing demand for air travel. Serving as an interface between ground access and airside activities, passenger buildings essentially provide a way to get large numbers of people into and out of aircraft safely and efficiently. The building design and layout has important implications for the airport authority, the airlines, and their passengers in terms of the cost and quality of the service provided. From the airports perspective, construction costs, operating and maintenance costs, concession revenues, and passenger satisfaction are all important. Passengers prefer minimal walking distances, adequate space, and adequate amenities. Airlines prefer the buildings to be inexpensive to build and operate, laid out such that the cost of maneuvering and operating their aircraft is minimized.

1.1 The New Design Environment

Following U.S. airline deregulation in 1978, several factors have combined to change the way passenger buildings should be designed. Deregulation unleashed competitive market forces

in the airline industry, allowing them to serve whichever geographic markets and airports they desire. This has resulted in increasingly volatile traffic levels at airports (de Neufville and Barber, 1991). At the same time, the availability of federal government funding has become less certain and airports have been placed under more pressure to be financially self-solvent. Consequently, airports have had to increase retail space and levy Passenger Facility Charges (PFCs) on airline passengers in order to support new construction. As passenger buildings are very expensive to construct and operate, the context of uncertain traffic levels and funding makes it imperative that they be designed for cost-effectiveness. This is especially the case for passenger buildings being developed and / or operated privately, a trend which is increasing. For example, managers at BAA Indianapolis LLC, the subsidiary of BAA Plc. operating Indianapolis/International, stress that cost-effective passenger buildings are an important part of their underlying value (Roberts, 2000). Reiss (1995) summarizes the emerging paradigm in passenger building planning and design.

The days of high-flying airport terminal projects are over. The 1980s philosophy of 'build it, and they will come' has been replaced by a new approach designed for a more conservative era in commercial aviation: Don't overbuild, but be prepared to change....Airport terminals in the 1990s are being designed and built to meet foreseeable demand – with very little uncommitted space. The speculative nature of terminal-building design and planning, dominant a decade ago, has been replaced by a philosophy more attuned to today's realities of consolidation of carriers, shared use of facilities, slowed passenger growth rates, and high debt loads for carriers and airport operators. This new philosophy of terminal design 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, undertaking renovation projects and finding interim uses for the conservative amount of spaces built in anticipation of future demand (Reiss, 1995).

1.2 The New Design Objective: Cost-Effective Capacity Provision

The environment of increasing uncertainty coupled with the need for cost-effective, conservative development provides the basic framework for analysis. Airport passenger buildings are complex systems. They are highly operational facilities with numerous

stakeholders, each of whom measures performance on different dimensions. In planning and designing this system, the fundamental decisions planners and designers face are how much capacity to provide, of what type, and when to provide it. Each of these factors affects how cost-effective the passenger building will be. Cost-effectiveness is thus an important objective of the emerging practice of passenger building design and planning.

Cost-effective planning and design is difficult because the loads placed on the facilities over time – passengers, vehicles, and aircraft – are highly variable. Peaking in demand results from the nature of airline traffic. Airlines schedule flight times with both passenger convenience and their own resources in mind. Demand peaks affect how much capacity needs to be provided for the peak periods and how well-utilized the facility will be at off-peak times. Variability leads to uncertainty in the level, pattern, and mix of traffic. In the short term, actual demand may vary from scheduled as a result of flight delays. In the long term, both the magnitude and mix of traffic and future operating procedures are unknown. There is a financial risk associated with providing capacity for uncertain demand – under-design can result in costly delays and lost opportunities, over-design can be wasteful if demand grows slower than expected, and mis-design can result in a capacity-demand mismatch. In other words, variability and uncertainty can lead to high costs. To maintain cost-effectiveness, planners must explicitly ensure that the capacity provided is responsive to the variability and uncertainty in current and future demand.

Since there are so many variables involved, planners have increasingly used simulation to test the performance of their design, identifying bottlenecks and sizing queuing and holding areas based on simulated delays and level-of-service experienced by passengers under several present and future operating scenarios. However, the facility's conceptual layout and operational capabilities must be defined before operations are simulated. The most important task from the

outset is to identify possible operating scenarios which capture the effects of variability and uncertainty, and then to design concepts which will be cost-effective under any of these scenarios. After all, the results of the simulation are only as good as the functional concept on which it is based.

Development of the passenger building concept should include both physical planning and operational planning, because operational needs dictate the physical design of the facility and the physical design can limit operational capabilities. In order for a facility to respond to variable and uncertain demand it must be designed to be flexible. This thesis takes a step back to look at this broader picture, providing a framework for thinking about flexibility in passenger building design as part of a strategy for cost-effective operations and long-term development.

1.3 Flexibility as a Way to Achieve Cost-Effectiveness

There is consensus in the industry that flexibility is a necessary component of a successful passenger building. While flexibility is almost universally considered to be a good thing, in practice it is often either left out of the calculations or misapplied, resulting in passenger buildings whose performance has been unsatisfactory over their lifetimes. There are two reasons for this: (1) the nature of the flexibility – why it is needed and how it can be implemented – may not be obvious, and (2) the benefits of the flexibility are usually expressed in qualitative terms, which can be argued against in the face of the immediate, quantifiable costs of providing that flexibility. The following quote, from one of the project managers coordinating the design of the new terminal at Washington/National, illustrates these points.

One of the biggest problems we all faced was the desire that the building be extremely flexible at very little or no additional cost. The nature of the flexibility was not always clearly understood. Additional space offers the greatest chance of success at meeting currently unspecified future needs. Space is also one of the most expensive ways to achieve flexibility (Feil, 1994).

Typically flexibility is seen as some sort of “intangible” factor, considered to be important but sometimes not worth the added expense to include it in facility design. But if used right, flexibility is actually a way to reduce total costs (or alternatively, improve net revenues) over the lifecycle of the facility. This defines the value of flexibility.

1.3.1 Theory of Flexibility

In the design and planning of complex, large-scale systems it is useful to think of two types of flexibility – operational and strategic. Operational flexibility gives managers the ability to better allocate resources in current operations by removing physical or institutional constraints that would otherwise limit their most cost-effective and efficient allocation. Its value is a function of the efficiencies it provides. Strategic flexibility allows managers to make decisions to adapt, expand, or otherwise change a system cost-effectively as conditions evolve over the long term. Its value depends on how much uncertainty exists in future conditions at the time of the initial investment decision, and the cost savings and revenue potential that can be achieved by deferring further decisions until the uncertainty has been reduced.

Real options is a quickly developing field of research on the provision and valuation of flexibility. Real options are flexibilities built into projects to provide managers with valuable allocation and decision-making ability. Several types of real options have been identified, including investment timing, abandonment, temporary shutdown, growth, input flexibility, output flexibility, and expansion options (Kulatilaka and Marcus, 1992). Flexibility usually involves a tradeoff between upfront capital costs and future reductions in capital and/or operating costs. Real options valuation, based on the valuation of financial options, has been used to value the benefits of flexibility as a function of the variability and future uncertainty in prices and

demand. This permits an informed tradeoff of the benefits and costs provided by the flexibility.

1.3.2 Flexibility in Other Industries

Work in other industries has focused on valuing the benefits of flexibility as a way to determine the optimal amount of flexibility to provide in a system. Flexible manufacturing systems (FMS) provide a good example of flexible design and planning. FMS allow manufacturing processes to be changed quickly, taking advantage of changing input prices and demands to lower costs and improve revenues. De Toni and Tonchia (1998) provide a comprehensive literature review on the different forms of flexibility in FMS. They differentiate the different forms of flexibility on various levels – product and process flexibility, machine and management flexibility, proactive and reactive flexibility, short term and long term flexibility, volume and mix flexibility. The task, then, is to match the right form of flexibility, in the right amount, with the problem at hand.

Numerous examples exist of flexibility as the core of company strategy. For example, the clothing manufacturer Benetton created a flexible manufacturing and distribution system to respond quickly to the rapid changes in fashion trends (Copeland and Weiner, 1990). Another example is the energy source for a power plant in which the turbines can be fired with either a gas-only burner, an oil-only burner, or flexible burner that can use either gas or oil. Value – potential cost savings – is derived from the ability to switch modes to take advantage of current prices of gas and oil, which fluctuate over time (Kulatilaka and Marcus, 1992).

Drawing parallels between FMS and airport passenger buildings is fairly straightforward. Instead of manufacturing widgets, passenger buildings “manufacture” capacity for different users – airlines, passengers, retailers, etc. Instead of machines which can be cheaply reconfigured to

take different inputs and produce different outputs, passenger building interior space and facilities can be reconfigured and reallocated according to variable demand profiles and growth rates. Section 1.4 further discusses the forms of flexibility most relevant in airport passenger buildings and the situations to which they can be applied to improve cost-effectiveness in current operations and future use and development.

1.4 Forms of Flexibility in Airport Passenger Buildings

In the context of airports, flexibility in passenger building design and planning can be used to improve current operations and hedge against future uncertainties. Designers have used many innovative approaches to making buildings more flexible, for example the use of carpet sections velcroed to the floor which are immediately replaced and cleaned at a remote location so that sections of the building do not have to be cordoned off for extended periods of time. In the case of Washington/ National designers kept utility systems and rights of way for air ducts separate so they could be maintained and expanded without disrupting each other, left space in critical locations for possible future elevators, and designed spaces to allow for shifts in airline locations and passenger characteristics (Feil, 1994). These kinds of flexibility are most important and should be used whenever it proves cost-effective.

This thesis, however, looks specifically at flexibility in providing and allocating capacity. Flexibly-designed buildings remain cost-effective both today and throughout their lifetimes because they can be operated, adapted, and expanded relatively inexpensively. This suggests that flexibility is not simply one item on a checklist of desirable attributes but is instead an integral part of a design because it can be used proactively as a way to manage present and future costs – it is both a means and an end. As there is often an upfront price to building an extra

mechanism or physical attribute into a facility to make its use and development flexible, the challenge becomes determining where and in what form flexibility should be provided, and valuing its benefits in comparison to its costs.

Figure 1.1 contains the identified forms of flexible capacity provision relevant to airport passenger buildings. The table is divided into two sections, flexibility for current operations and flexibility for future development. It cites examples of each form of flexibility and some sources in the literature which mention them. Underlined sources include quantitative analysis of how much flexibility is needed and / or how to trade off the benefits and costs.

1.4.1 Spare Capacity

Planners provide spare capacity when there is uncertainty and growth in demand. Technological uncertainty warrants the provision of a spare, or backup, system in case a new technology does not work. For example, the automated baggage system for Denver/International was a new, sophisticated, and untested technology. The original plans had no provision of a backup tug and cart system to be used while the bugs were being ironed out of the automated system. As a result, the technical problems of the automated system delayed the airport's opening for 16 months, at an estimated cost of \$500 million (de Neufville, 1994). A manual tug and cart system was put in place after several months of delay, to be kept as a backup system after the automated system came online (Airport Forum, 1994). Had the backup system been there from the start, perhaps some of the delay costs could have been avoided.

When demand is stochastic, spare capacity is provided as fixed capacity beyond that required by expected or scheduled levels. In the short term, spare capacity provides flexibility in capacity allocation when flights are delayed. For example, extra gates on hand can be assigned

Time Frame	Forms of Flexibility	Driver	Problem	Solution	Example	Literature
Current Operations	Spare Capacity / Backup System	Schedule Uncertainty	Delays	Spare Capacity	Extra gates	<u>Steuart (1974)</u> <u>Hassounah & Steuart (1993)</u> <u>Bandara & Wirasinghe (1988)</u> <u>de Neufville (1976)</u>
		Technological Uncertainty	Failure, Delays	Backup System	Transporters Denver baggage system	<u>de Neufville (1994)</u>
	Multifunctionality	Peaking	Underutilization	Sharing	Departure Lounges Aircraft Mix Airlines Int'l / Domestic Spare Capacity	<u>Wirasinghe & Shehata (1988)</u> <u>Gaudinat (1980)</u> , <u>de Neufville (1976)</u> <u>Beinhaker (1975)</u> <u>Blow (1995)</u> <u>Fordham (1995)</u> <u>de Neufville (1976)</u>
	Expandability	Peaking	Seasonality	Non-fixed Capacity	Transporters	<u>de Neufville (1976)</u> <u>Kuckuck (1975)</u> <u>Oppenheim (1978)</u>
Future Use and Development	Multifunctionality	Uncertain Mix	Capacity/Demand Mismatch	Adaptability	Departure Lounges Aircraft Mix Airlines Int'l / Domestic	
		Uncertain Operations	Obsolescence	Adaptability	Int'l / Domestic hubbing	
	Expandability	Uncertain Demand	Risk of Under- or Over-Design	Modularity, reserve space	Phasing Expansion	<u>Beinhaker (1975)</u> <u>Bluestone (1979)</u> <u>de Neufville (1991)</u> <u>Aberdeen (1994)</u>

Figure 1.1. The Different Forms of Flexible Capacity for Passenger Buildings

to flights if a string of delays has kept their scheduled gates occupied. Airport and airline planners provide spare capacity implicitly, keeping gate utilization lower than 100% to provide breathing room in case of delays in the schedule.

Long term growth implies that future demand will be larger than that which exists today. Since capacity provision is a “step function,” there will always be some over-capacity to grow into when planning for the future. Additionally, some extra capacity is necessary beyond what would be required if demand growth were certain to cover unexpected surges (Manne, 1961). However, how much over-supply is of critical importance. Full build-out of capacity for demand expected 30 years down the road is not cost-effective for several reasons. For one, the facilities will be underutilized during the interim years of growth. Secondly, growth and rates of growth are neither certain nor guaranteed. Thirdly, while average total demand growth may be discernable, growth of different sectors, which may require different facilities, is less predictable. The negative consequences of overbuilding provide much of the motivation for the discussion that follows. Growth and uncertainty warrant supplying capacity in smaller increments with the ability to expand, as opposed to providing long term spare capacity up front to cover growth. Some portion of the capacity should be compatible with different sectors or users so it can be reallocated to either according to their future needs.

1.4.2 Expandability

Expandability is probably the most familiar form of flexibility. It is most useful in providing flexibility when long term growth is uncertain. Airport planners realize that future demand is uncertain, staging the development of the passenger buildings in phases. Capacity can be added in the future if necessary, but is not paid for now. Economies of scale in construction

and operation may be lost when capacity is provided in smaller initial increments. There is an additional price to pay to make the facility expandable – the building structure and functional organization must be initially designed so it can be expanded and empty space must be provided on which to expand. Modularity and independence of functions is important to keep the entire landside and airside system in balance, so that different facilities and services can be expanded without affecting the overall functionality or capacity balance of the landside/airside system. The benefits of having this capability in the future typically outweigh the additional upfront costs. In short, phasing of capacity expansions is cost-effective planning.

Analytical techniques for sizing and timing capacity expansions exist, but most do not deal effectively with uncertain growth. Demand must be modeled as a known random process – for example, a Bachelier-Weiner diffusion process (Manne, 1961) or a birth / death process (Freidenfelds, 1980) – to make the problem mathematically tractable. This limits its applicability from a practical standpoint. Aberdein (1994) conducted a related study for planning the sizing and timing of power plant investment using decision analysis. Depending on the growth rate and the variability of demand, it proved more cost-effective to build in smaller increments which could be expanded than in larger increments, sacrificing economies of scale for flexible decision-making. This supports the need for strategic planning, rather than master planning, of capacity provision (de Neufville, 1991).

Expandability is of paramount importance to the airport passenger building development. However, thinking of flexibility only in terms of the ability to expand for future growth is limiting. Expansion should be the last resort in providing capacity – first, attempts need to be made to get the most out of existing facilities. As with flexible manufacturing systems and types of real options, different situations require different forms of flexibility.

Expandability for short term needs is similar to short term spare capacity. However, it comes in the form of non-fixed capacity such as transporters or remote bus gates, requiring less capital investment but higher operating costs than fixed capacity. If fixed capacity is provided less than the peak demand, non-fixed capacity allows managers to “expand” capacity in the short term to cover peaks. This provides flexibility because it can be “turned off” when demand is low, reducing costs. de Neufville (1975) discusses an analysis trading off the capital and operating costs of transporters to determine their optimal provision at airports experiencing seasonal or daily peaking. Transporters have other benefits as well. They can cover delays during peak periods and serve as temporary capacity while new facilities are being planned to accommodate growth. Kuckuck (1975) provides a critical analysis of the practicality of transporters and some of the hidden costs they bring, concurring with de Neufville that they be provided at not more than 20 or 30 percent of total capacity.

1.4.3 Multifunctionality

Expandability allows for growth and spare capacity is used to cover delays. Assuming these have been provided in the right amounts, the best design-operation concepts are those which allow some facilities to be shared between different users. In order to be shared facilities must be designed with enough flexibility to serve the requirements of multiple users and functions – they must be multifunctional. Multifunctional facilities offer more value per dollar invested than those which only perform one function. For example, the sunblocking devices on a large window wall at Las Vegas’ new D Gates double as catwalks for maintenance personnel to wash the windows. Since they serve two functions simultaneously, they are more valuable to the airport for their cost. Similar value can be derived from capacity that is multifunctional.

Oftentimes passenger building facilities and spaces are designed to serve one function. For example, separate departure lounges may be provided for each aircraft gate, separate gate positions for different size aircraft, separate facilities for different airlines, and different gates (or entire buildings) for domestic and international traffic sectors. Separation simplifies capacity management because it allows different functions and users to be neatly compartmentalized for service and planning. There are benefits to doing and it is useful in many places. For example, separating landside and airside buildings permits independent expansion and growth of each and centralized ground access, as originally implemented in the design of Tampa/International which opened in 1971. Similarly, separating arrivals and departures roadways on different levels simplifies vehicular access and egress of the passenger building.

However, when facilities are subject to peaks and uncertainty in demand, planning and designing each function independently requires more overall capacity than is needed. Facilities serving only one use cannot easily adapt to changing conditions, leading to high re-development costs in the future. Complete separation of users and functions is not cost-effective design.

Multifunctional facilities can be shared by different users to offset their peaks and can be reallocated to different users in the future. The benefits are reduced overall space requirements and avoidance of costly expansion to meet future demand. Depending on the extent of peaking and uncertainty, the benefits of shared use may justify only a portion of the facilities to be multifunctional. The rest of the facility can be dedicated to a particular single function as usual.

1.5 Organization of Thesis

As the use of spare capacity and expandability are both common and accepted practice, the thesis focuses primarily on multifunctional space and facilities. Figure 1.2 shows the

organization of the thesis. The next three chapters focus on using this flexibility to mitigate the effects of peaking (Chapter 2), schedule uncertainty (Chapter 3), and future uncertainty (Chapter 4). The advantages of multifunctionality are illustrated through shared departure lounges and shared gate positions, but could as well be applied to other areas of the passenger building and landside system including the ticket counters, baggage claim, parking facilities, curbside, etc. Chapter 5 provides recommendations on implementing multifunctionality considering that, in most cases, all three factors are present. It also looks at the implications of providing for flexible capacity provision through both multifunctionality and expandability. Two appendices provide examples and descriptions of shared lounges and international/domestic swing gates at airports around the world.

Driver	Issue	Solution	Value Comes From ...	Chapter
Variability and Uncertainty in Demand, Technology, Industry Structure, etc.	Separate Facilities: Underutilization and Risk of Inappropriate Design	Multifunctional Space and Facilities	Cost-effective Use and Development	1
Peaking	Peaking of Different Users' Demand	Sharing of Facilities to Offset Peaks	Higher Utilization = Saved Space = Saved Cost	2
	Sequencing of Aircraft for International / Domestic Flows	Sharing of Facilities allows for Changeable Aircraft Designation	Fewer Wasted Resources and Increased Aircraft Availability	2
Uncertainty	Short Run: Variations from Schedule (e.g. Delays)	Sharing Spare Capacity to Cover Delays	Reducing Cost of Spare Capacity	3
	Long Run: Uncertainty in Future Use and Growth	Adaptability: Multiple Possible Future Uses	Avoiding Future Construction	4
Peaking and Uncertainty	Conflicts Between Above Factors	Swing Gates and Swing Space	Integration of Above	5

Figure 1.2. Summary and Organization of Thesis

Chapter 2. Peaking in Demand: Reducing Costs Through the Sharing of Facilities

This chapter discusses how shared space can reduce the costs of the passenger building when there is peaking in traffic demand. Designing a facility to serve more than one category of user provides operational flexibility, allowing its use to change as the demand pattern changes. When the peak periods of two or more users do not coincide, the total capacity required to accommodate the peaks is reduced if they can share the facility. The savings in required space both reduces construction and maintenance costs and shortens the passengers' walking distances.

Flexibility is important in planning and design when demand is uncertain, because it allows managers to better respond to change. In particular, multifunctionality allows facilities to be reallocated to different users in the future given their actual future demands. Multifunctionality is also useful if the demand is certain but some incompatibility between different users prevents the most efficient overall allocation of facilities. Multifunctional space and facilities are designed specifically to overcome these incompatibilities to allow for sharing, which provides greater overall efficiency and reduces total costs.

Sharing of facilities is possible in all areas of the passenger building – the curbside, interior holding and circulation spaces, and aircraft gate positions. In fact, many of the facilities on the airport are already shared. The airport circulation roadway is shared by both automobiles and buses; ticket counters, security checkpoints, baggage claim, and concessions are shared by passengers on different flights; concourse corridors are often shared by departing, arriving, and transfer passengers. However, some facilities are provided exclusively to certain users. Curb frontage is often allocated to different users – taxicabs, courtesy shuttles, transit buses and private automobiles may each have a designated waiting area. Aircraft gates may be designed to serve only one size of aircraft. Entire passenger buildings may be assigned to only international

or only domestic traffic. This disparity in the use of facilities provokes the following questions: When and where does it make sense to share facilities? If sharing makes sense, how much of the facility should be shared?

2.1 The Nature and Implications of Peaking

Facilities should be shared between different categories of users when there is significant peaking in their demand over time. Peaking in traffic is a natural result of airlines' flight schedules, which in turn determines the demand for aircraft gates and passenger circulation, processing, and holding facilities. Several factors influence how airlines schedule their flights, including convenience for passengers, coordination of hubbing operations, and scheduling windows. Peaks resulting from many flights scheduled in the same time periods are not unlike highway rush hours – the hours before and after the work day in which many people travel to and from work. Peaking is also experienced at the weekly and monthly levels, depending on the market and the sector of traffic – Fridays are busier than Sundays, and August is busier than January, etc.

The problem posed to the planner is the degree to which the peaks govern the design level of capacity. By definition, peak periods are accompanied by off-peak periods. If capacity is provided to serve all or most of a daily peak, gate positions and interior space will be underutilized during the off-peak portions of the day. This is illustrated in Figure 2.1, a Gantt chart showing the occupancy of five gates throughout the day; black areas represent gate occupancy while gray areas represent times when the facilities are unoccupied. During the morning peak five flights all require gates at the same time. During off-peak times only two or three gates are needed to accommodate the scheduled demand – the remaining gates are not in

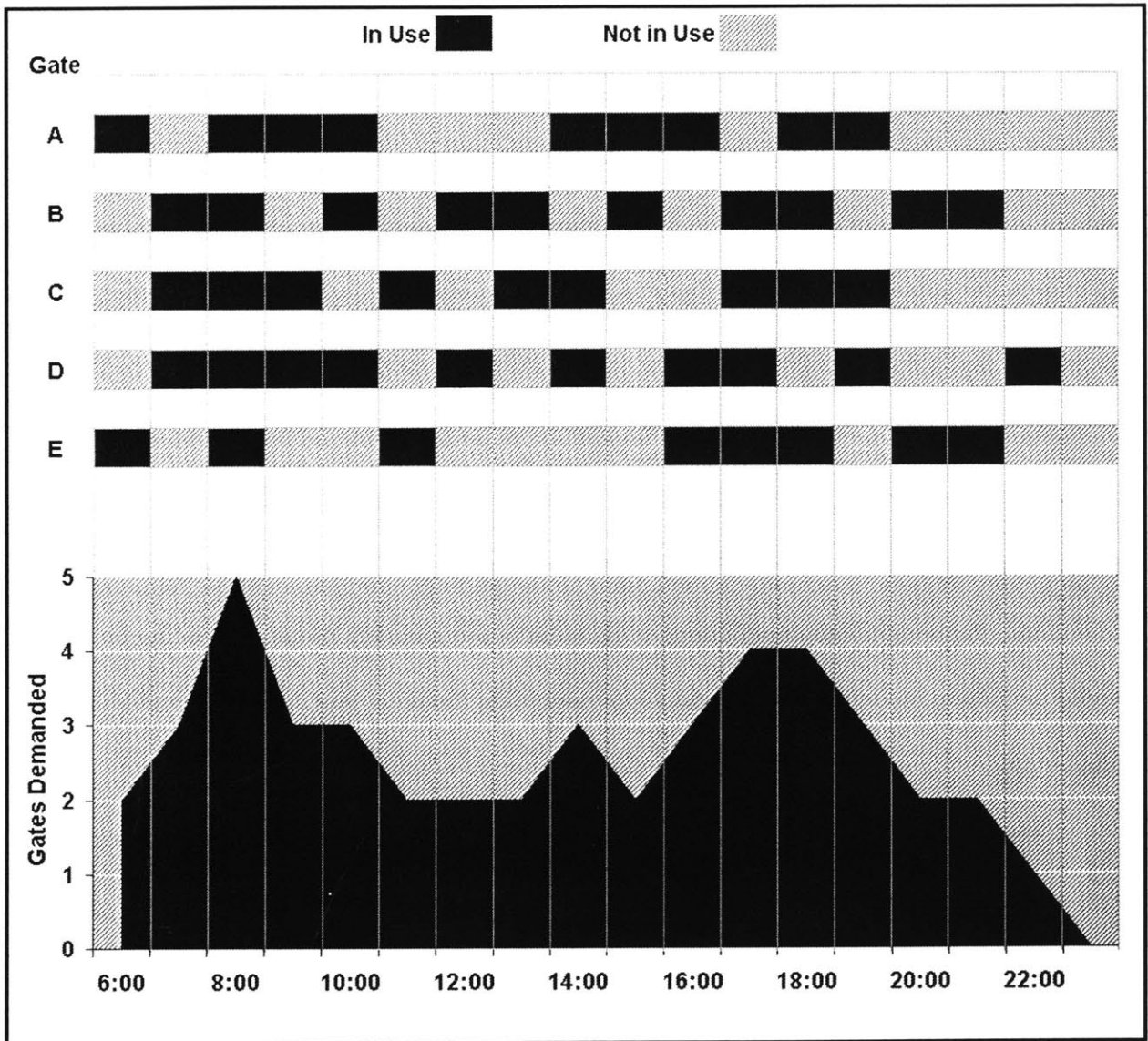


Figure 2.1. Effect of Peaking on Utilization of Gates

use during this time. When facilities are underutilized, the airport operator receives lower revenues from airlines per gate, lower concessions revenue per gate, and faces higher operations and maintenance cost per passenger. Airport operators would like to find ways to minimize this costly underutilization by avoiding the provision of seldom-used space and facilities.

The effects of peaking are compounded when the physical design or operating policy limits a facility to serve only one user; such as only domestic or international traffic, or an individual airline. Each user's facility is designed for its own peak, but is empty during its off-peak time. However, if the operating policy allows space to be shared and the facility is designed to be multi-functional, the peaks for user can fill in the off-peaks of other users. This reduces the total capacity required since the sum of the collective peaks is always less than the sum of the individual peaks, as Figure 2.2 indicates.

There are two ways to design multifunctional facilities to allow for sharing. The space could be designed to be "generic," essentially providing a blank slate which does not favor any user over another. This is a case of passive sharing; no "switch" needs to be thrown as users change. "Swing space" is a more active form of sharing, in which space and facilities can be allocated to different users through movable partitions and systems of sterile corridors and holding spaces.

The advantages of shared facilities are illustrated through two applications, shared departure lounges and shared use aircraft gates. Departure lounges serve passengers from one or more flights and from one or more airlines, depending on the passenger building's design and operational policies. Possible groupings for aircraft gate position assignment include by airline, aircraft size, and flight sector (e.g. international or domestic). Figure 2.3 shows this.

In order to allow for sharing between flights, airlines, aircraft types, or flight sectors,

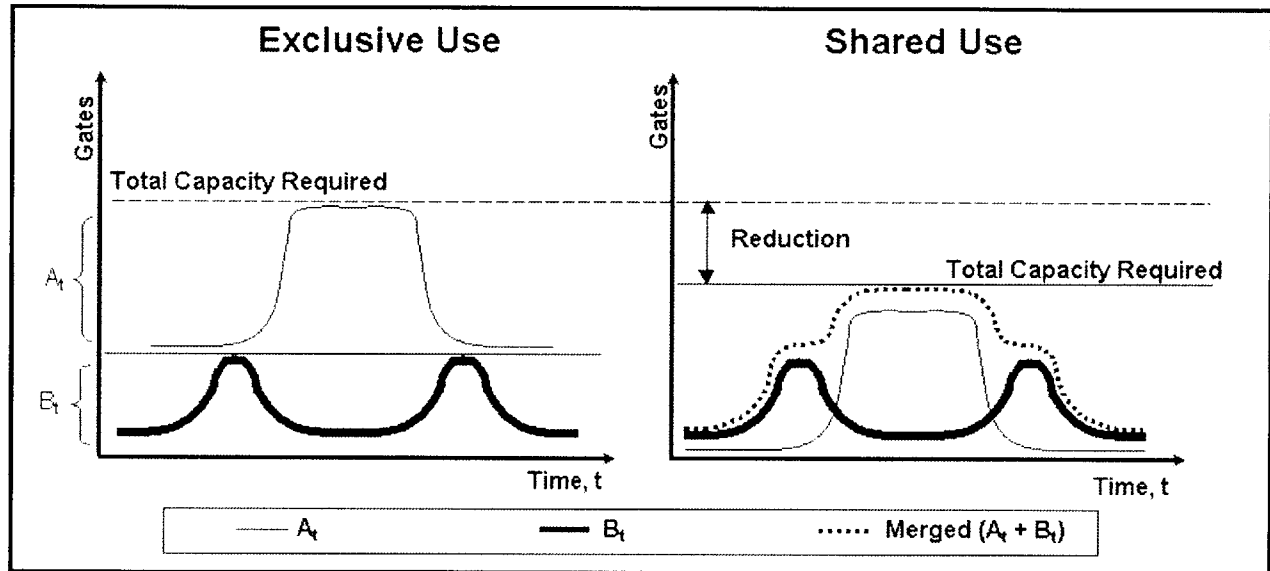


Figure 2.2. Reduction in Space Requirement due to Shared Use of a Facility

Departure Lounge shared by...	Gate Positions shared by...
Passengers - Flights from Same Airline	Different Airlines
	Aircraft Size - One Airline
	Aircraft Size - Different Airlines
Passengers - Flights from Different Airlines	International / Domestic - One Airline
	International / Domestic - Different Airlines

Figure 2.3. Possible Groupings of User Categories for Sharing

flexibility must be introduced into the physical design and the operational plan. The users sharing facilities may not be physically or institutionally compatible. Multifunctional facilities are specifically designed to overcome these incompatibilities. The benefit is savings in total space required, at the cost of additional design to overcome the physical and institutional incompatibilities. In situations where there is a high degree of variability and peaking, the lifecycle benefits of providing this flexibility will likely outweigh the upfront costs. The challenge is to get the best benefit-cost tradeoff by including the optimal amount of flexibility – i.e., determining how much of the facility should be shared and how much should be provided exclusively to individual users.

2.2 Shared Departure Lounges

Departure lounges are sized for some percentage of the maximum expected passenger accumulation, depending on the size of aircraft. The number of people in the lounge peaks as result of the rates at which passengers enter the lounge to wait for their flight and exit the lounge to board the aircraft. When (or soon after) the passengers begin to board the aircraft – typically 20 to 40 minutes prior to its scheduled departure time – the total accumulation peaks and then rapidly declines during the boarding process. Figure 2.4 shows this.

Outside the U.S., airport designers often place one departure lounge per aircraft gate in order to provide each departing flight its own seating area. The reasoning is that this eliminates the possibility that passengers will be missing at boarding time, potentially delaying the flights' departure (Fordham, 1995). However, when there are no flights scheduled to depart from a given gate its lounge space is empty. This setup leaves departure lounges in many passenger buildings underutilized during large portions of the day. In addition to cost-ineffective provision

of capacity, decentralized facilities result in fewer passengers in empty parts of the building to patronize nearby retail and concessions establishments, which is revenue-ineffective.

Shared departure lounges, which are common at many U.S. airports, can reduce the total lounge space required by a given number of adjacent aircraft gate positions. They are multifunctional in that they provide seating capacity to passengers assigned to different flights. Figure 2.5 shows an example of the physical setup of a passenger building with individual lounges at each gate compared to a shared departure lounge serving several gates. As the flights scheduled for these gates do not depart at exactly the same time, their passengers can share the same seating space while only a few passengers occupy the lounge waiting for other flights. The total space needed to serve all of the flights will be less than that needed if each gate had its own lounge. In addition to the benefits of reduced space requirements shared use lounges also provide retail establishments more exposure to potential customers because the passengers are all centralized in one location rather than being dispersed at separate lounges along a long concourse or pier (Fordham, 1995). Figures 2.6 and 2.7 show shared lounges at Las Vegas/McCarran. Appendix I contains several more examples.

Since passengers for several flights are all waiting in the same place, any particular flights' passengers may not be distinguishable. It is therefore of utmost importance that in large shared lounges information be provided to passengers about flight times and locations visibly and clearly through signs and PA announcements to avoid any confusion. New information technologies such as radio frequency (RF) chips in passengers ticket sleeves or frequent flyer cards may allow missing passengers to be found anywhere in the building when their flight is boarding, eliminating the worry that passengers may become lost and flights may be delayed if each gate does not have its own lounge.

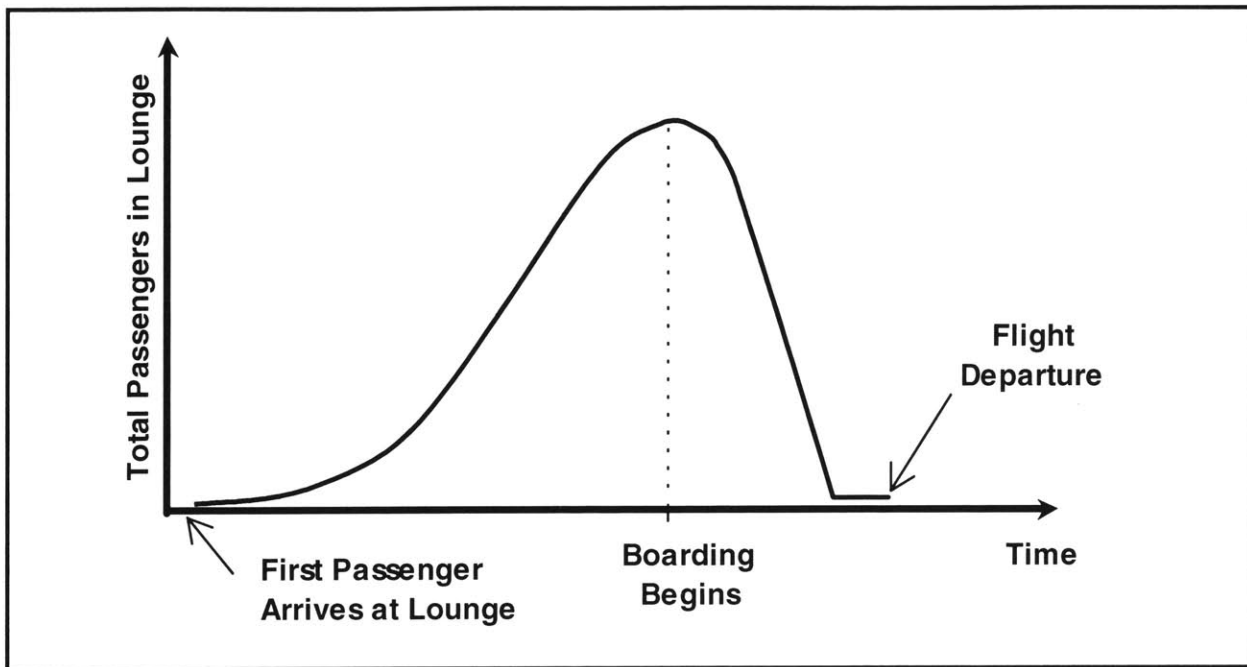


Figure 2.4. Accumulation of Passengers in Lounge for a Single Flight

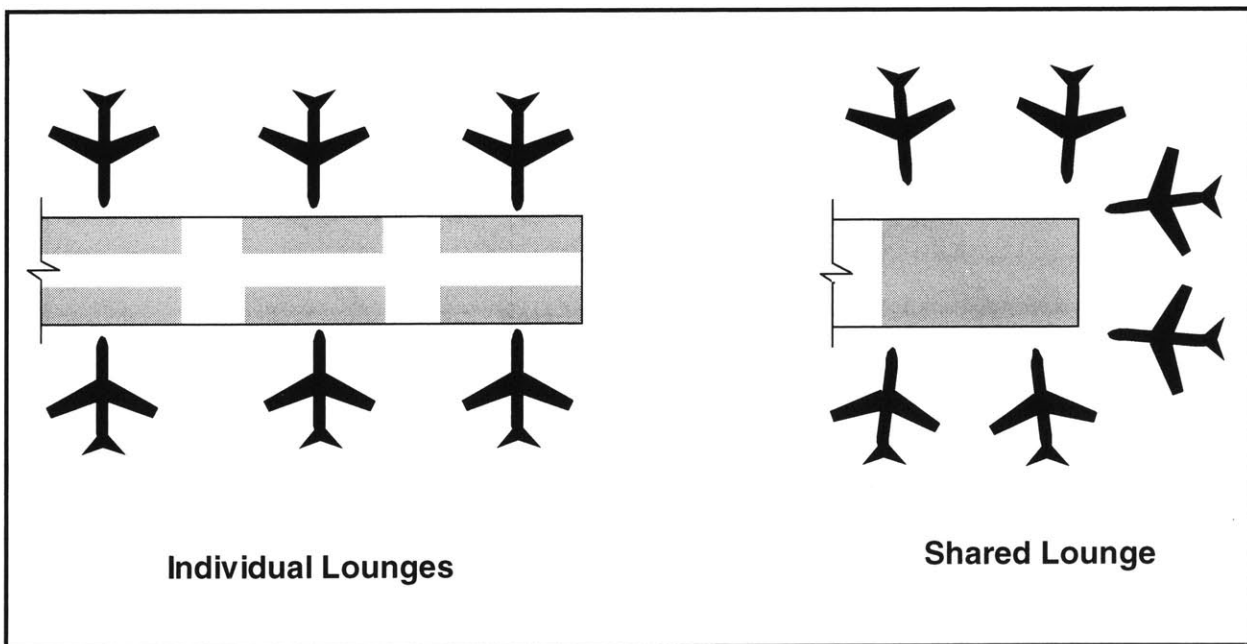


Figure 2.5. Diagrams of Individual Lounges and Shared Lounge

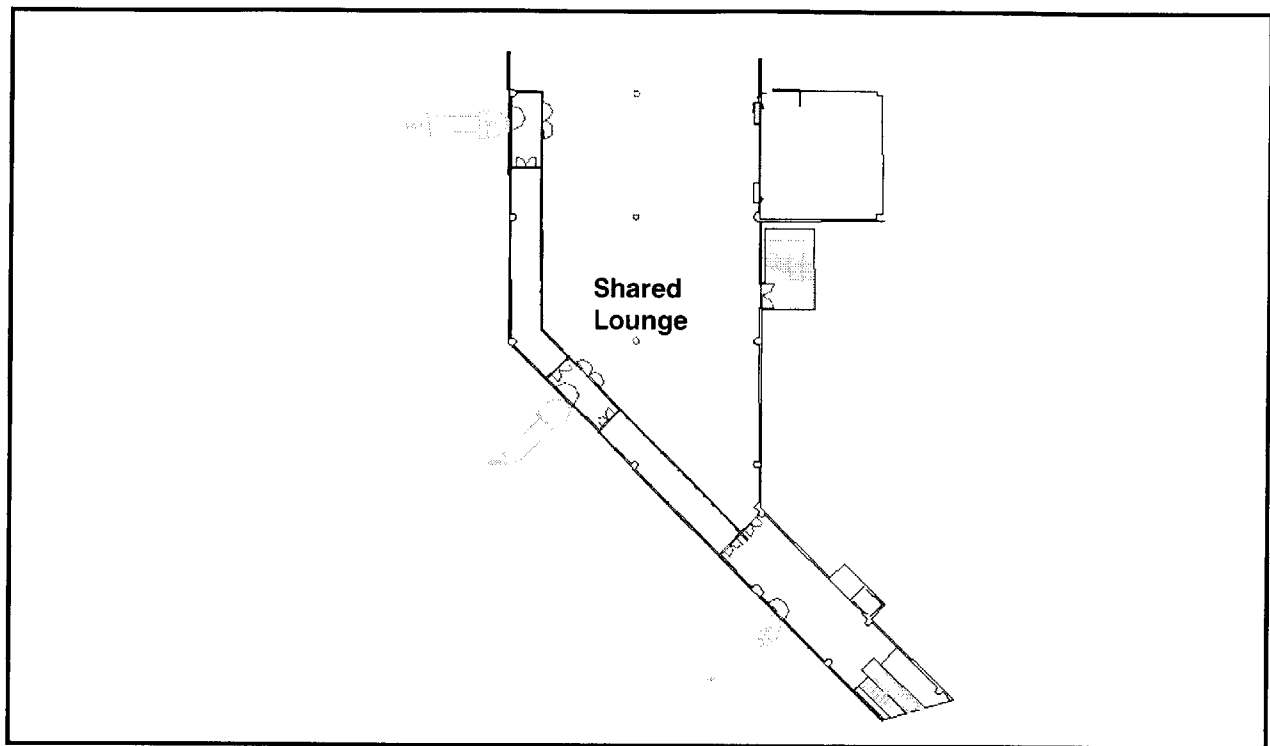


Figure 2.6. Shared Departure Lounge at Las Vegas/McCarran Terminal 2

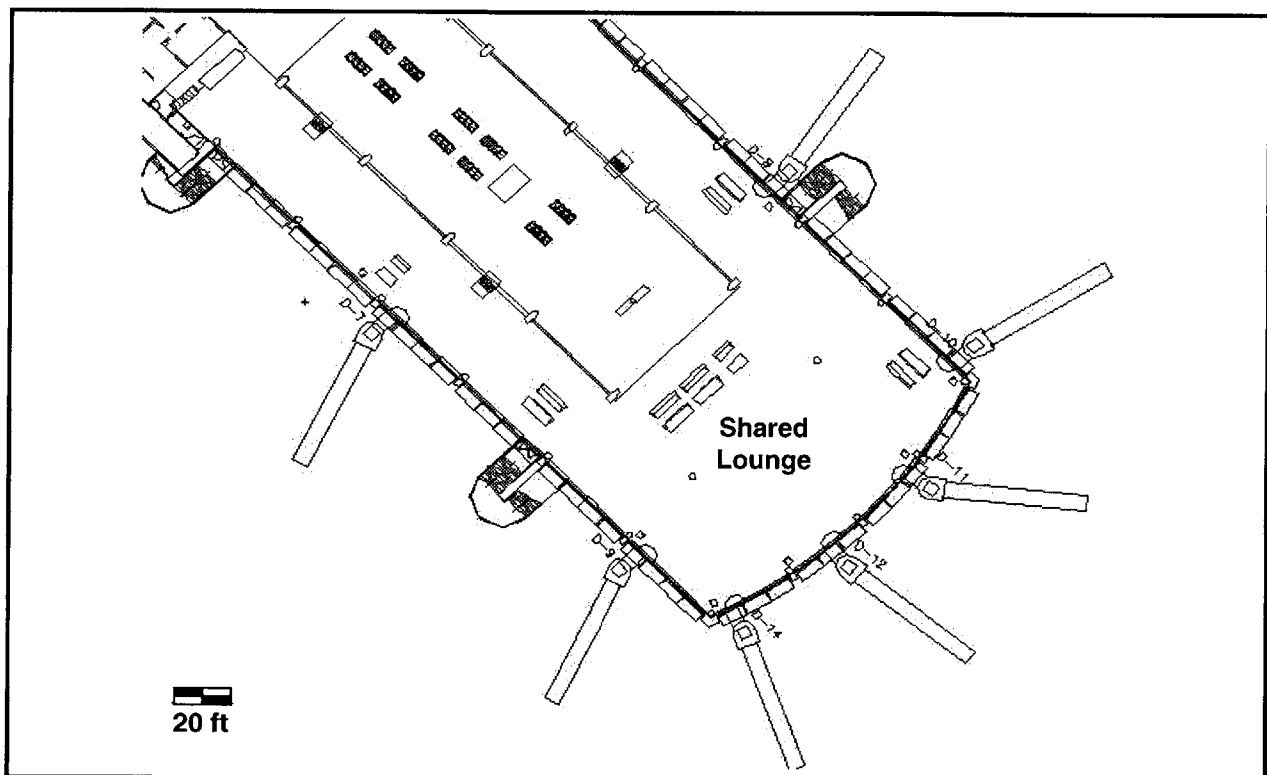


Figure 2.7. Shared Departure Lounge at Las Vegas/McCarran D Gates

2.2.1 Reduction in Total Lounge Space

The reduction in total lounge space needed can be very significant, typically between 10 and 50% depending on the situation. The space reductions depend on the degree of overlap between the flights' lounge space requirements over time. This analysis uses a simple spreadsheet model to estimate space savings as a function of the number of flights sharing the lounge during a bank and the time between their departures. The assumptions used in this analysis include the flights' gate occupancy times, passenger arrival function, boarding rate, and boarding time prior to departure. The spreadsheet model is described in section 2.2.2. What is important here is the result of the analysis – shared lounges lead to significant total space savings. The space savings is the difference between the space required by the sum of each flights' maximum requirement (if each gate has its own lounge) minus the space required for a lounge shared between several gates.

$$\text{Percent Savings} = \frac{(\text{Sum of Each User's Max. Demand}) - (\text{Max. of All Users Summed Demand})}{(\text{Sum of Each User's Max. Demand})} \quad (1)$$

The current U.S. Federal Aviation Administration (FAA) guidance recommends:

when a lounge area serves more than one aircraft gate position, the estimated total lounge area shown in Table 5-3 may be reduced 5 percent for each aircraft gate position, up to a maximum of six gates. (FAA 1988)

So, a lounge shared by two gates would require 95% of what would be required for two individual lounges, 90% for three gates, 85% for four gates, etc. Figure 2.8 shows the space required for a shared lounge as a percentage of that required for individual lounges, for this model versus the FAA. Figure 2.9 plots the reduction factors. The results emphasize several important points. For a given inter-departure time, the more flights sharing

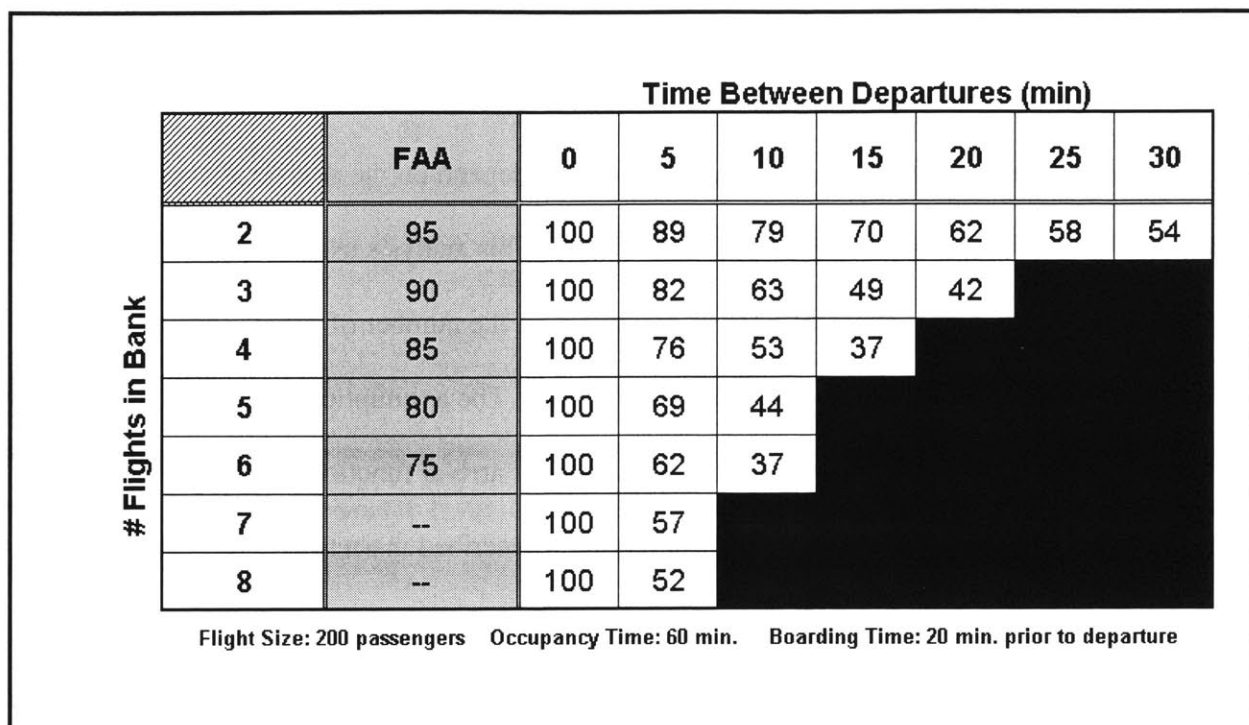


Figure 2.8. Space Needed for an N-gate Shared Lounge as % of N Individual Lounges

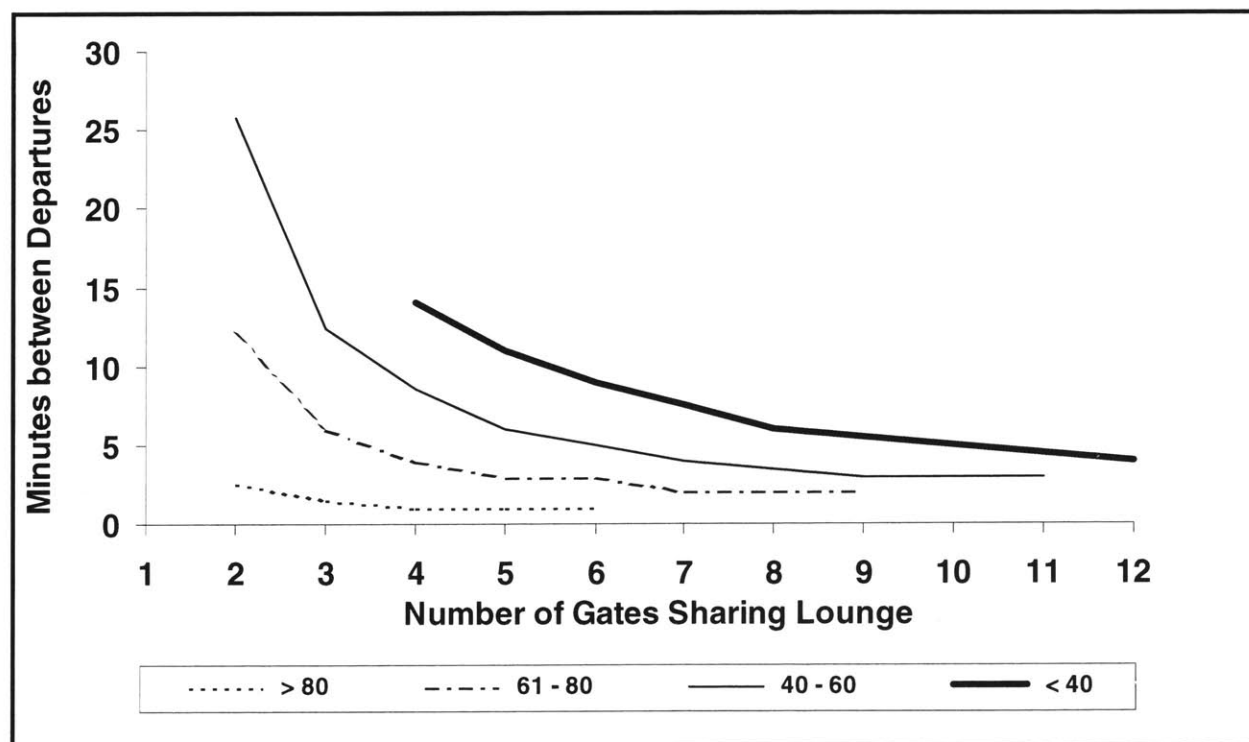


Figure 2.9. Space Needed for an N-gate Shared Lounge as % of N Individual Lounges

the lounge the greater the space savings. However, this savings exhibits diminishing marginal returns to the number of flights – beyond about six flights sharing the lounge, there is little further savings. For a given number of flights sharing the lounge, space savings increases as the time between flight departures increases. Conversely, if all of the flights departed at the same time (i.e., no time between departures), there would be no overlap between peak demands and no reduction in total space required. The question for design and policy is how many gates to combine in one lounge and how large to size it. Six gates appears to be the upper bound on the number sharing the lounge from the perspective of space reduction. From a practical viewpoint, a lounge shared between more than six gates could also confuse passengers listening for the boarding call for their flight.

In addition to the number of flights and the time between their departures, the occupancy time of each flight's passengers in the lounge affects the potential savings. Increasing occupancy time decreases the potential savings because the accumulation of passengers for each flight stretches over a longer time period, resulting in more overlap between space needs and less savings. These results are plotted against the FAA guidance for several combinations of occupancy time and interdeparture time in Figures 2.10 and 2.11. The size of aircraft and flight sector (international vs. domestic) only affects savings because the required time passengers arrive before departure and boarding time must be increased. For large interdeparture times, the more flights sharing lounge the greater the average savings. For small interdeparture times, average savings is nearly independent of the number of flights.

FAA guidance is overly conservative, underestimating possible savings per additional gate by 3% to 25%. Additionally, it misses the important point of diminishing marginal returns to the number of gates sharing the lounge.

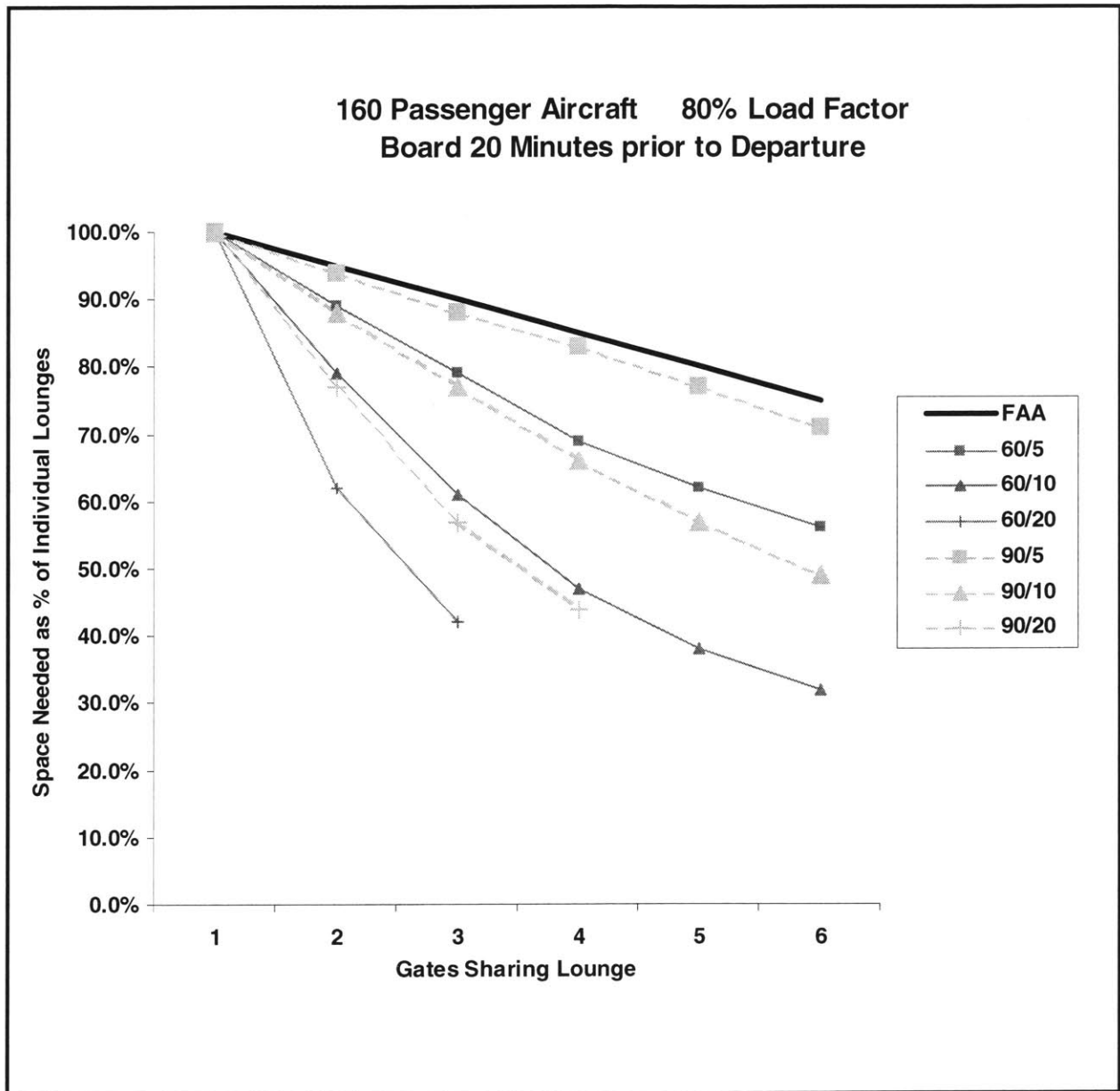


Figure 2.10. Space Reduction by Occupancy Time/Interdeparture Time (Narrowbody)

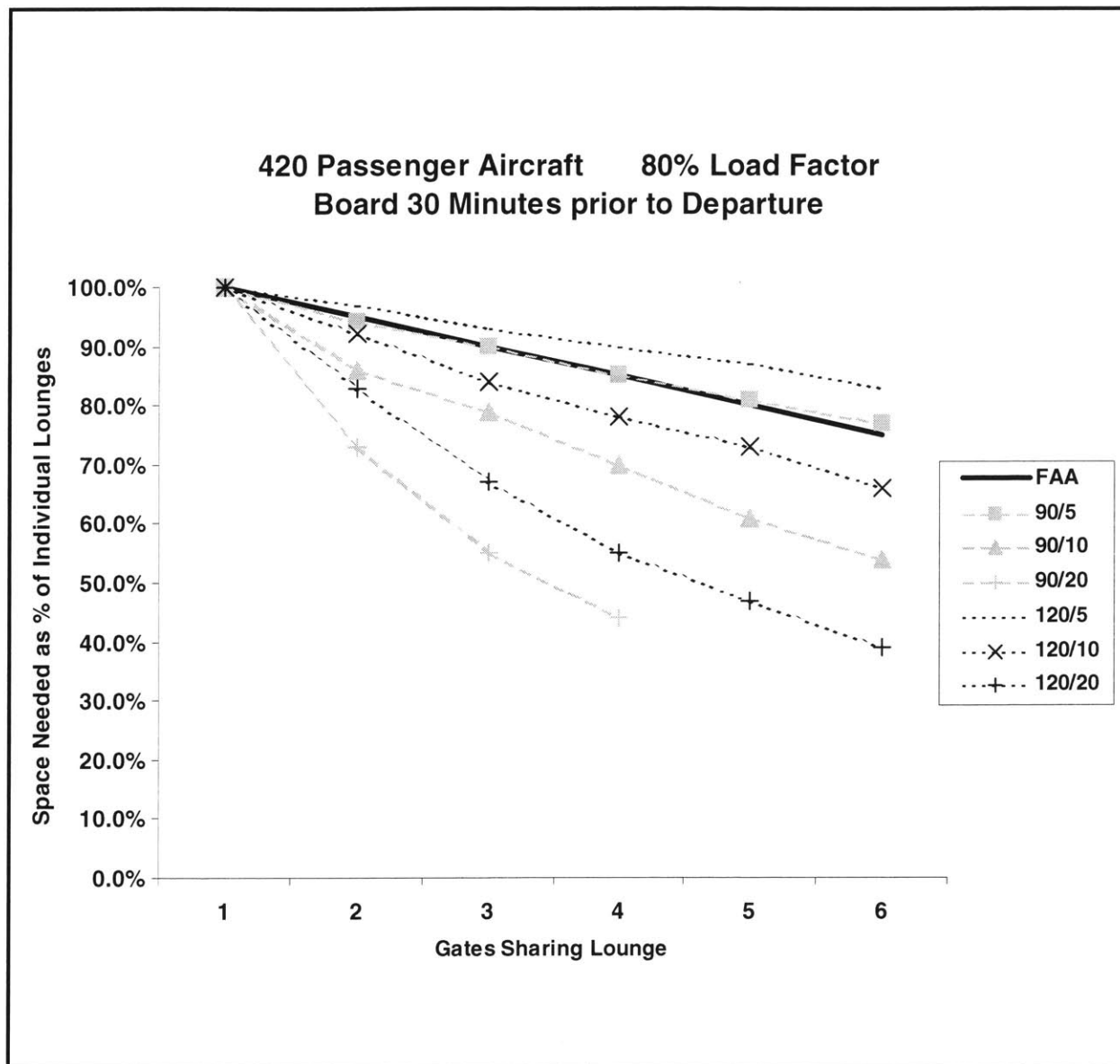


Figure 2.11. Space Reduction by Occupancy Time/Interdeparture Time (Widebody)

2.2.2 Calculation: Example Spreadsheet for Sizing Shared Departure Lounge

Wirasinghe and Shehata (1988) analyzed a lounge shared by identically-sized flights, finding that the maximum potential savings from sharing use of a lounge is about 50%. The authors consider the lounge to be shared between flights if any passengers from subsequent flights are in the lounge prior to the beginning of the boarding process of the first flight in the bank. The average inter-departure time is the number of minutes prior to boarding the first passenger arrives in the lounge for the first flight divided by the number of flights, N , occupying the lounge during this period. On the assumption that the departure rate peaks during this period and is symmetrical, they derive the space requirement in equation (2).

$$\text{Percent of Space Required} = 0.5 + \sqrt{\frac{1}{3N}} \quad (2)$$

However, the potential savings is not explicitly considered a function of the spacing between flight departures – this is implicit in the calculation based on the number of flights. In equation (2) the authors essentially define the maximum savings possible for a given number of flights sharing the lounge.

Instead, the spreadsheet model explicitly considers the effect of the inter-departure times on the potential savings, because this defines the degree of overlap. An additional difference is that this analysis considers flights to be sharing the lounge as long as the first flight in the bank has not completely boarded. Some time is allowed after the boarding process begins in which passengers using the lounge for another flight are considered to share with a flight whose passengers have already begun to board. The result is a slightly higher savings for a given number of flights in the spreadsheet versus that presented in equation (2).

The spreadsheet makes it easy to vary these factors to see how they affect the result, and then how to design the lounge given a reasonable set of assumptions. The goal here is not to recommend actual dimensions for shared lounges (because the assumptions needed to do this vary by airport), but instead to highlight which assumptions need to be made and how to do the calculations given those assumptions.

The size of a shared lounge depends on assumptions about the accumulation of passengers waiting for a given flight in the lounge over time and the spacing between their flights' departure times. The assumptions used in this analysis are shown in Table 2.1. Departure lounges are typically designed to serve some percentage of the maximum number of people expected to simultaneously be waiting for their flight to depart, which typically occurs around the time the boarding process begins, as shown in Figure 2.4. In this example, the passenger arrival time distribution and the rate at which the aircraft is boarded were empirically estimated from data collected for several flights at San Francisco/International by Horonjeff and Paullin (1969). The first passenger is assumed to arrive 60 minutes prior to the flight's departure and the boarding process is arbitrarily set to begin 20 minutes prior to departure. They estimated the arrival process as the cumulative number of passengers by time t in minutes for a 120-passenger flight as:

$$\text{Passengers Arrived as of } t = (-1.78) + (0.72)t - (0.02)t^2 + (0.0025)t^3 - (0.00003)t^4 \quad (3)$$

They estimated the average aircraft boarding rate as 14 passengers per minute.

Suppose there are several flights in a 60 minute bank with different departure times. Figure 2.12 shows a sample spreadsheet set up at 5-minute time intervals, given the assumptions described above. These values differ slightly from the analysis with 1-minute intervals, but can

Table 2.1. Assumptions Needed for Spreadsheet Analysis

Number of Passengers per Flight	120
Arrival of First Passenger @ Lounge Prior to Departure	60 minutes
Time Prior to Departure Boarding Process Begins	20 minutes
Passenger Arrivals to Lounge as a Function of Time t (minutes)	$(-1.78) + (0.72)t - (0.02)t^2 + (0.0025)t^3 - (0.00003)t^4$
Boarding Rate	14 passengers per minute
Number of Flights Sharing Lounge	4
Time Between Flight Departures	15 minutes
Space per passenger at LOS C	1.0 m ² per passenger

Time (min.)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	MAX
Flight 1	0	2	6	12	20	32	46	62	75	11	0	0	0	0	0	0	0	0	0	0	0	0	75
Flight 2	0	0	0	0	2	6	12	20	32	46	62	75	11	0	0	0	0	0	0	0	0	0	75
Flight 3	0	0	0	0	0	0	0	2	6	12	20	32	46	62	75	11	0	0	0	0	0	0	75
Flight 4	0	0	0	0	0	0	0	0	0	0	2	6	12	20	32	46	62	75	11	0	0	0	75
																							300
Merged Schedule: Sum Flights 1, 2, 3, 4	0	2	6	12	22	38	58	84	113	69	84	113	69	82	107	57	62	75	11	0	0	0	113

Figure 2.12. Sample Spreadsheet of Total Passengers Simultaneously in Lounge

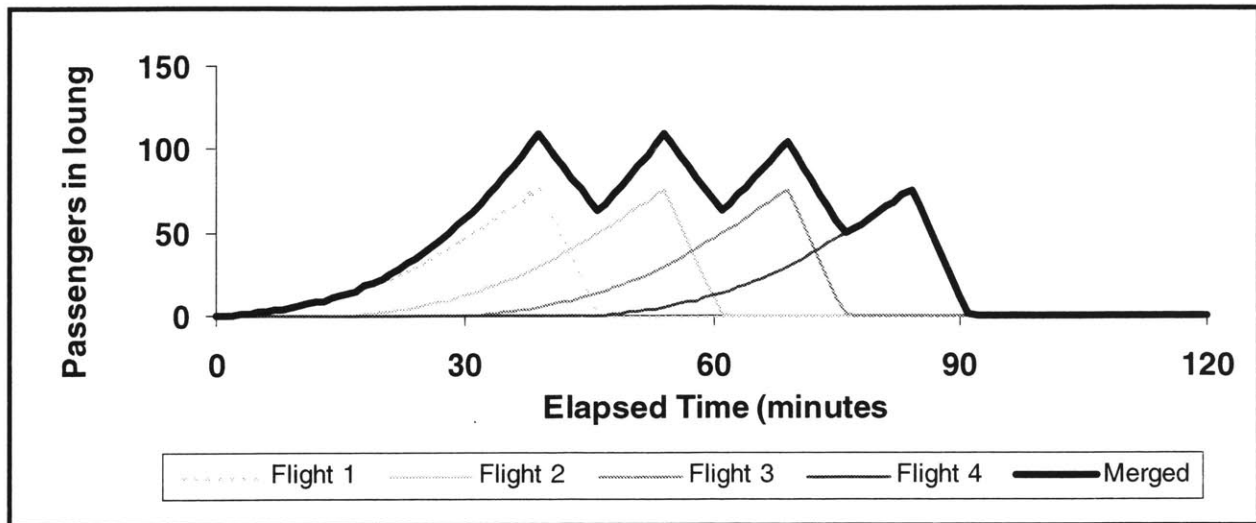


Figure 2.13. Total Passengers for whom Space is Required in a Shared Lounge

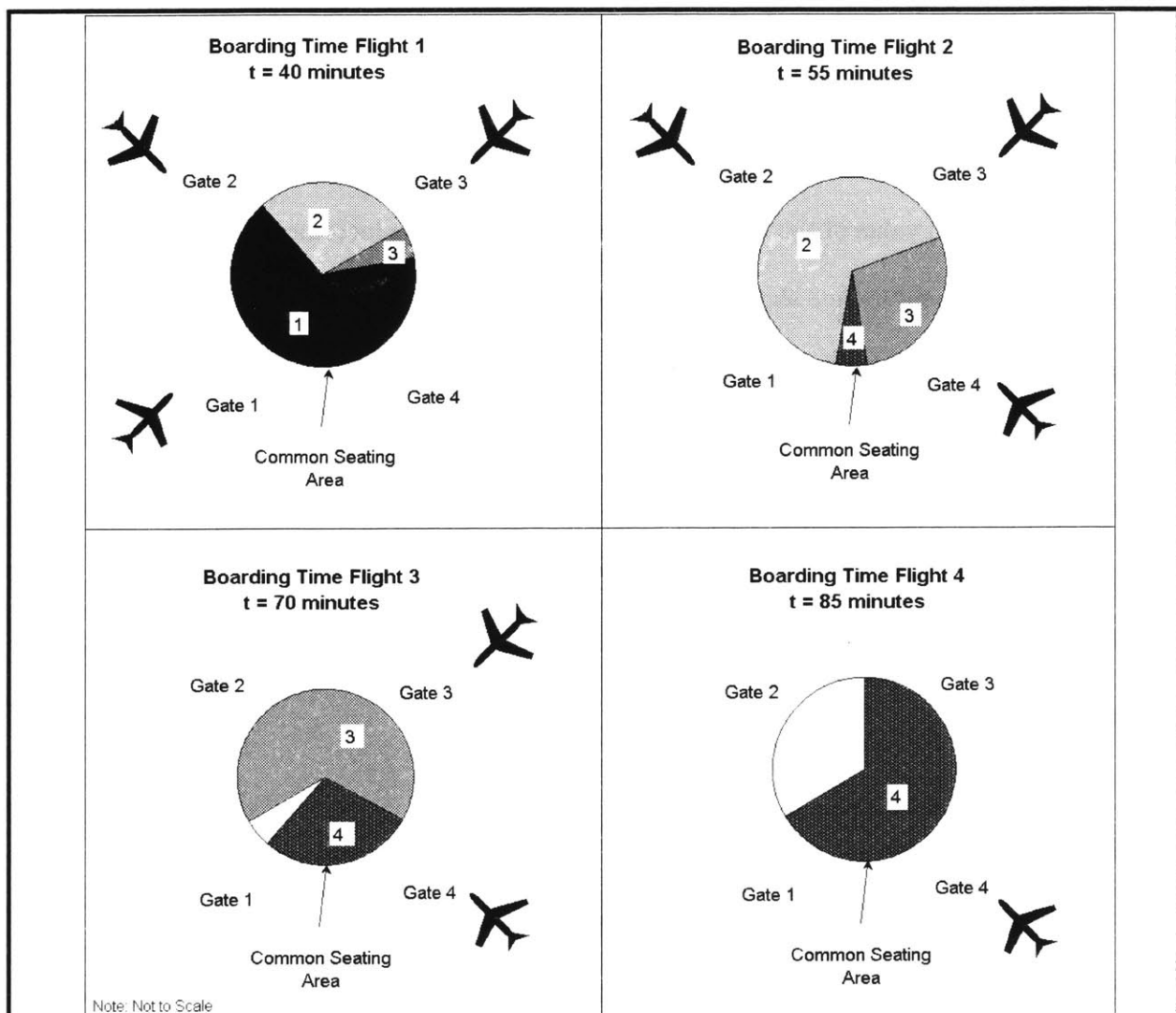


Figure 2.14. Occupancy of Shared Lounge over Time (15 min. between departures)

be assumed to be about the same. Each flight's peak accumulation of passengers peaks occurs at different times and therefore their need for seating space overlaps, as plotted in Figures 2.13 and 2.14 for a departure lounge shared by four gates whose flights are scheduled to depart in 15 minute intervals.

In sizing the lounge, the first step is to determine the maximum accumulation of passengers for each flight, in this case 75 passengers. Assuming LOS C requires 1.0 m² per passenger (IATA, 1995), if individual lounges are provided at each gate a total of 75 m² is required for each lounge, and the total space need is the sum of that needed for each of the four lounges, 300 m². In the case of the shared lounge, the total accumulation of passengers is the sum of the accumulation for each flight in each time period, referred to as the "merged" schedule. The dark line in Figure 2.13 represents the total accumulation for all the flights over time. The maximum value of the total accumulation over all time increments is 113. At Level-of-Service C the shared lounge should be designed for approximately 113 m². The space savings is the difference between the amount of space required with the lounge shared between several gates and the total space required if each gate has its own lounge. In this case, at its maximum accumulation the shared lounge takes up only 37% of the space of individual lounges, which represents a space and cost savings of 63%. This analysis was done for several combinations of number of flights, interdeparture time, and occupancy time to create Figures 2.8 through 2.11.

2.3 Shared Gate Positions

The motivation for sharing gates between different users and the procedures for determining how many to share are similar to those for the shared departure lounge. Sharing

gates and other kinds of facilities can be more complicated because of the costs of creating the flexibility to share. In the case of departure lounges, the entities sharing the space – people – are compatible. That is, they can all fit in the same seat, no matter to which flight they are assigned. More generally, there are physical or institutional constraints on the sharing of facilities, requiring upfront costs to build a multi-functional facility that allows for sharing.

Depending on the degree to which different users' peak periods do not coincide a significant reduction in total gates required is possible, as Figure 2.2 illustrates. Reducing the number of gates has several benefits in the development of new passenger buildings: lower construction cost; lower maintenance cost; better utilization of space; and shorter walking distances for passengers. For an existing facility, shared use is beneficial because it is an effective way to increase capacity without having to construct new gates. As discussed previously, Figure 2.3 shows different ways to categorize the users sharing gates. The gate sharing could be between aircraft sizes or international / domestic traffic within an airline, or between airlines.

2.3.1 Sharing by Airlines

Outside the United States, airport authorities frequently control gate use rather than airlines. Different airlines sharing gates is common although national flag carriers typically have their own space, as British Airways has its own building at London/Heathrow, Japan Airlines at Tokyo/Narita, Air France at Paris/Charles de Gaulle. In the United States, airlines competing for traffic prefer to have their own facilities which they control. Lease agreements may grant the exclusive use of space and facilities. Gaudinat (1980) explored the possibility of gate-sharing

between airlines for Boston/Logan, finding that about 10 to 50 percent reductions could be achieved if non-competing carriers shared space.

While different airlines may not want to share gate positions and terminal space for competitive reasons, at capacity-constrained airports it may be one of the only ways to improve utilization and increase capacity. In these situations, perhaps airlines can maintain exclusive use of facilities to cover their base traffic needs and share the remainder for their peak needs. Additionally, PFC-financed gates cannot be exclusive use of one airline (Arthur, 1999).

Enabling airlines to share ticket counters and gate lounges in today's information-driven environment requires Common Use Terminal Equipment (CUTE) and changeable display screens. CUTE systems offer a standardized platform on which different airlines can connect to their own information systems and "plug-in" any additional components they require. They have been installed extensively worldwide and in some airports in the U.S. including international ticket counters and gate check-in facilities at Houston/Intercontinental, Las Vegas/McCarran, Los Angeles/International, New York/Kennedy, and Orlando/International. Changeable display screen technology would allow the logos to change depending on which airline is currently occupying the space. In the privately operated Terminal One at New York/Kennedy, television monitors display these logos. Changeable display screen technology, which would offer more flexibility than TV screens, are currently being developed for other applications but could be used here.

Airlines in the U.S. are not particularly fond of CUTE systems, because they perceive CUTE to decrease their own ability to gain market share against other airlines (World Airport Week, 1997). However, when capacity constraints or costs are an issue, shared use becomes more and more acceptable, because the potential savings are substantial.

Samuel Ingalls, Las Vegas / McCarran (LAS) business office manager, says "I can't think of a single carrier that wouldn't say our system is an unqualified success. They have so much more operating flexibility. Carrier attitudes are changing." Especially when considering savings claims. CUTE installation cost \$10 million, compared with an estimated \$10-12 million to build one gate. Ingalls says LAS needed 10-15 fewer gates because of CUTE. (Feldman, 1999)

2.3.2 Sharing by Aircraft Size

The mix of aircraft is one of the most influential factors in passenger building design requirements. Aircraft gates that can be used by different size aircraft are useful when there is peaking and uncertainty in the aircraft mix. It is common for some portion of the gate positions to be designed this way. Part of American Airlines' 2000-2001 renovations to its facilities at Boston/Logan will allow aircraft of different sizes to use the gates (AMR Corp, 2000).

Gate stands designed to accommodate only narrowbody aircraft require less space than those for widebody aircraft. By designing a gate to serve both narrowbody and widebody aircraft, flexibility in gate assignment is gained at the expense of the total number of gates that can be provided in a limited amount of space. To make the gates usable by different size aircraft, loading bridges must be flexible and adjustable, and the apron must be laid out such that different sized aircraft can be serviced easily. Another obvious consideration is that the size of a departure lounge is related to the size of the aircraft using that gate. Shared use departure lounges make it easier to accommodate a changing flight mix at gates that can serve more than one size aircraft because they can "absorb" the change easier than an individual lounge at each gate. Chapter 4 discusses this further in the context of future uncertainty in the mix of aircraft.

2.3.3 Sharing by International / Domestic

The mix of international and domestic traffic is also a critical factor in facility requirements. Most countries require that incoming international passengers have no physical

contact with domestic passengers and other people, ensuring that security, passport, and customs – such as the U.S. Federal Inspection Services (FIS) – are not compromised. As a result of the special security and facility requirements associated with international flights, common practice separates international and domestic arrivals in different buildings. This practice simplifies the operation of the passenger building – it is easier to ensure international and domestic passengers have no contact if they are in completely different buildings. While there are some benefits to separating international and domestic traffic, there are also some very strong disadvantages. Separate facilities reduces the flexibility managers have in allocating gates to flights, because each facility can only serve the type of traffic for which it is designed but no other.

Several factors are making combined international / domestic passenger buildings more attractive now than in the past. Hansen and Kanafani (1988) point out that domestic and international traffic are highly complementary. Following deregulation, airlines created hub-and-spoke route networks and concentrated flights to and from their hubs, allowing passengers from a wide range of origins to transfer to an equally wide range of destinations. One of the outcomes was for large domestic hub airports to become international gateways and international gateways to become domestic hubs. In an era of increasing competition between airports for traffic, airlines

...have increasing flexibility (though less than in the domestic context) in choosing from which gateways to offer what service. The close coupling between domestic and international services amplifies the impact of these choices on airport traffic, and thus on facility requirements and revenue streams at gateway airports. (Hansen and Kanafani, 1988)

Carriers have increased the reach of their route networks by simply partnering with other countries' international airlines. Several large airlines primarily serving different regions have created alliances in which they code share, share other resources, and offer seamless services to passengers to the point that they appear almost as a single, large airline. Sharing of resources

and facilities between alliance partners impacts their utilization of passenger buildings. Alliance partners may want to share facilities. Blocks of adjacent space in passenger buildings may be allocated to the members of an alliance, who would share facilities between themselves to improve passenger service levels while at the same time improving operating efficiency and cost-effectiveness. Already, alliance partners at Toronto/Pearson and other airports are being relocated so they are all in the same terminal (Greater Toronto Airport Authority, 2000).

International / domestic swing systems provide the capability of serving both international and domestic traffic in the same building, improving facility and resource utilization. Swing gate systems typically consist of sterile corridors with a series of interlocking doors to route passengers to the FIS or into the public concourse area depending on whether their flight is international or domestic. The design of the swing gate system depends on who needs to be separated according to the country's regulations. For example, in the U.S. departing international passengers do not have to be separated from domestic passengers, so gates for departing international flights can be assigned to a "domestic" building. However, in most other countries international and domestic departing passengers must be separated, and sterile enclosed departure lounges can be provided at each gate as well. Figures 2.15 to 2.18 show examples of international/ domestic swing systems.

The most flexible sterile corridor system design routes international arriving passengers to a separate level so the swing gate can be used without affecting the rest of the adjacent gates (Fordham, 1995). However, the additional costs of a separate floor must be considered when analyzing the benefits and costs of this type of design. Typically when international capability has been added into domestic buildings after the fact, enclosed glass partitions and sterile corridors along exterior walls are built around the gate door. If several gates access a single

sterile corridor they can affect the other gates' flight capabilities, which is less desirable but still beneficial.

International / domestic swinging need not be limited to gate positions – swing baggage claim facilities have been developed as well, for example, at Wellington, New Zealand and Toronto, Canada. A movable wall partition allows the claim unit to be allocated to international or domestic depending on the needs at the time. Extra caution must provide that on the operations side international and domestic bags come in no contact prior to Customs inspection.

While most U.S. international buildings do have this domestic capability built in – domestic flights can deplane into the international building and be directed to a domestic baggage claim device, provided typically for charters – it is not the stated purpose of the facility to operate this way explicitly as a strategy to improve utilization. As many U.S. airports are organized around the unit terminal concept, an FIS in each domestic building will result in less efficient FIS processing. But if an international terminal is constrained, FIS facilities in separate unit terminals may be necessary, as was the case at Los Angeles/International. Outside the U.S., it is generally the case that international and domestic buildings are separated completely.

On the facility utilization level, swing gates are valuable because there is peaking in both international and domestic traffic demand. Depending on the geographic location of the airport and the markets it serves, there are certain windows of time in which airlines schedule international arrivals and departures which make the flights convenient to passengers and fit in with the rest of the route system and schedule. Oftentimes it is the case that international arrivals buildings are empty for much of the day, with the exception of these scheduling windows. There is a good chance that the international and domestic peaks do not coincide, as was the case with

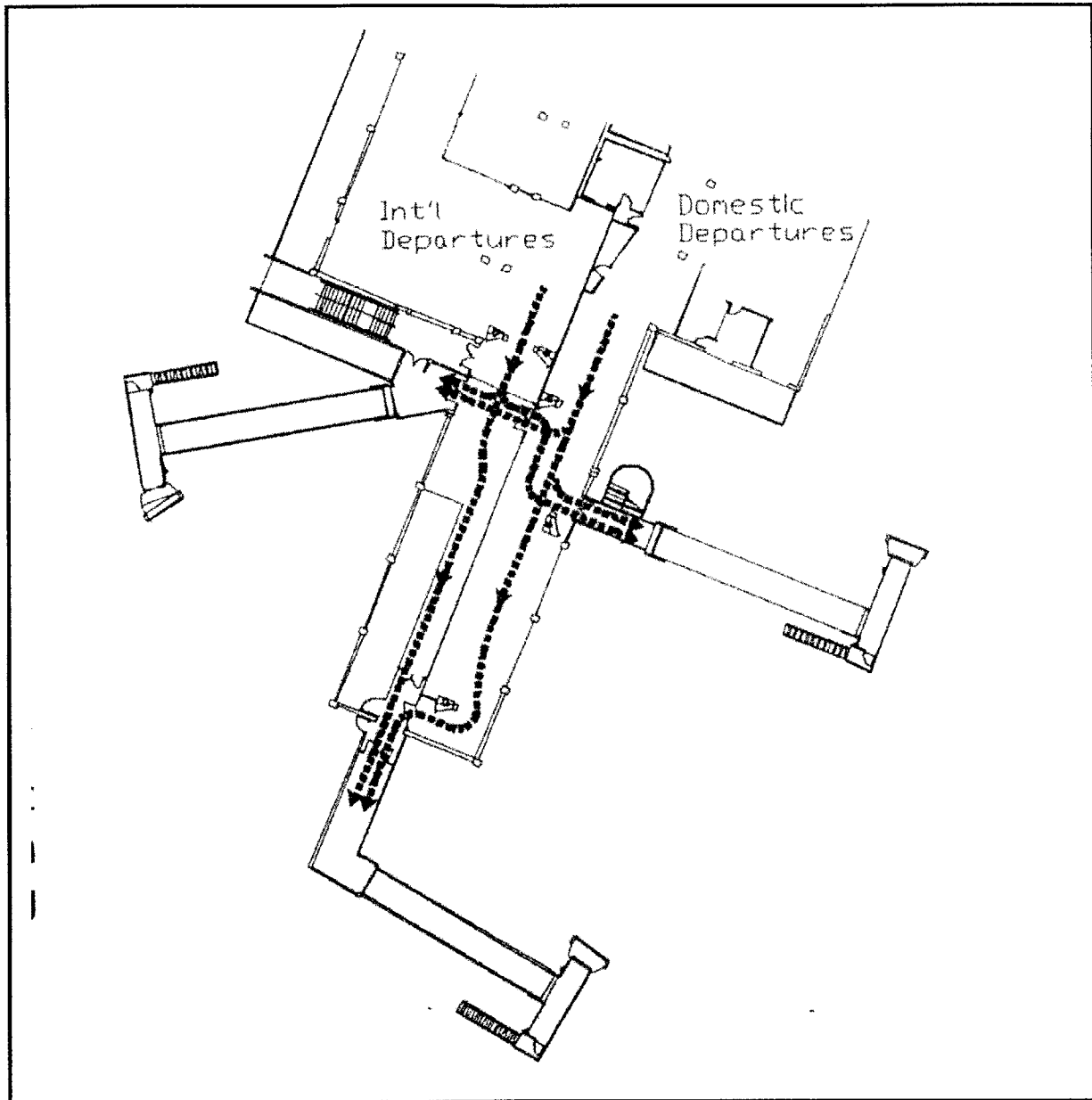


Figure 2.15. International/Domestic Swing Gate Example - Wellington, New Zealand

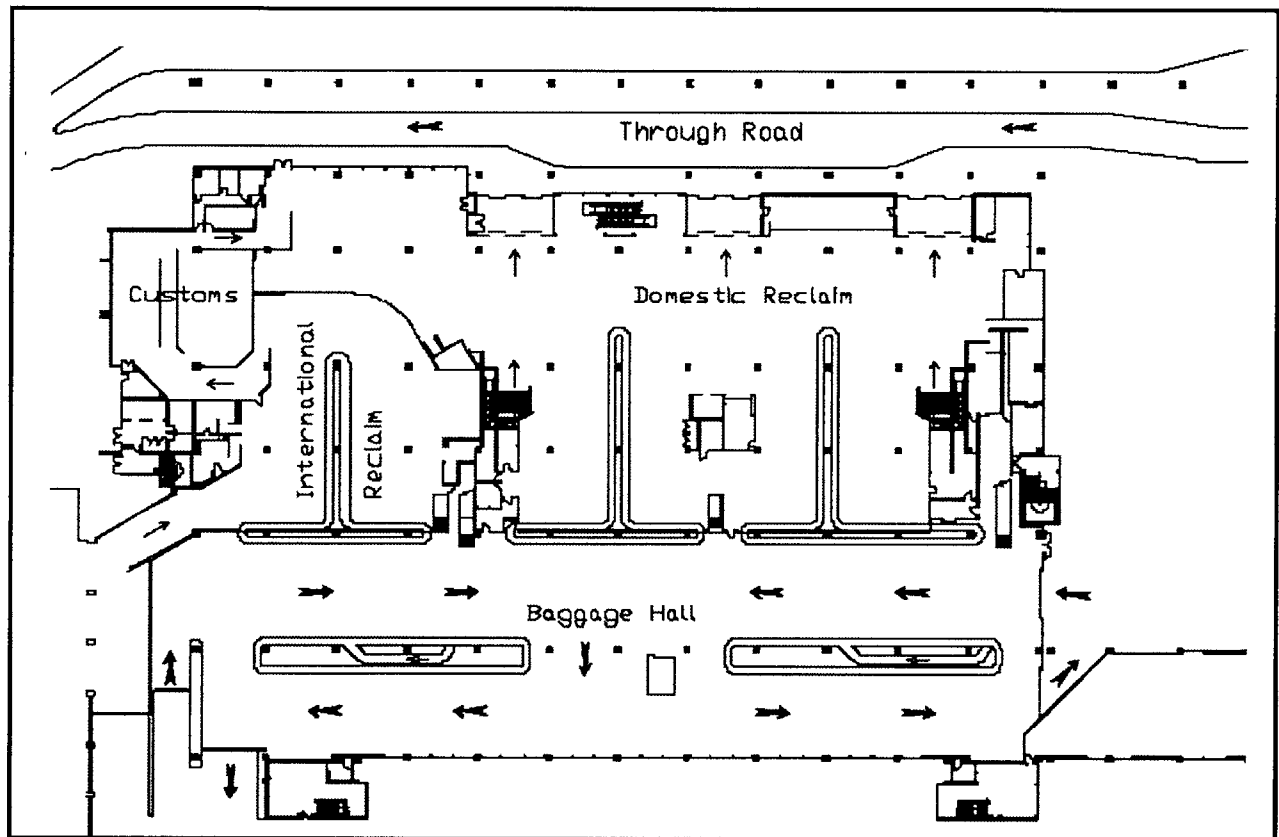


Figure 2.16. International/Domestic Swing Baggage Claim - Wellington, New Zealand

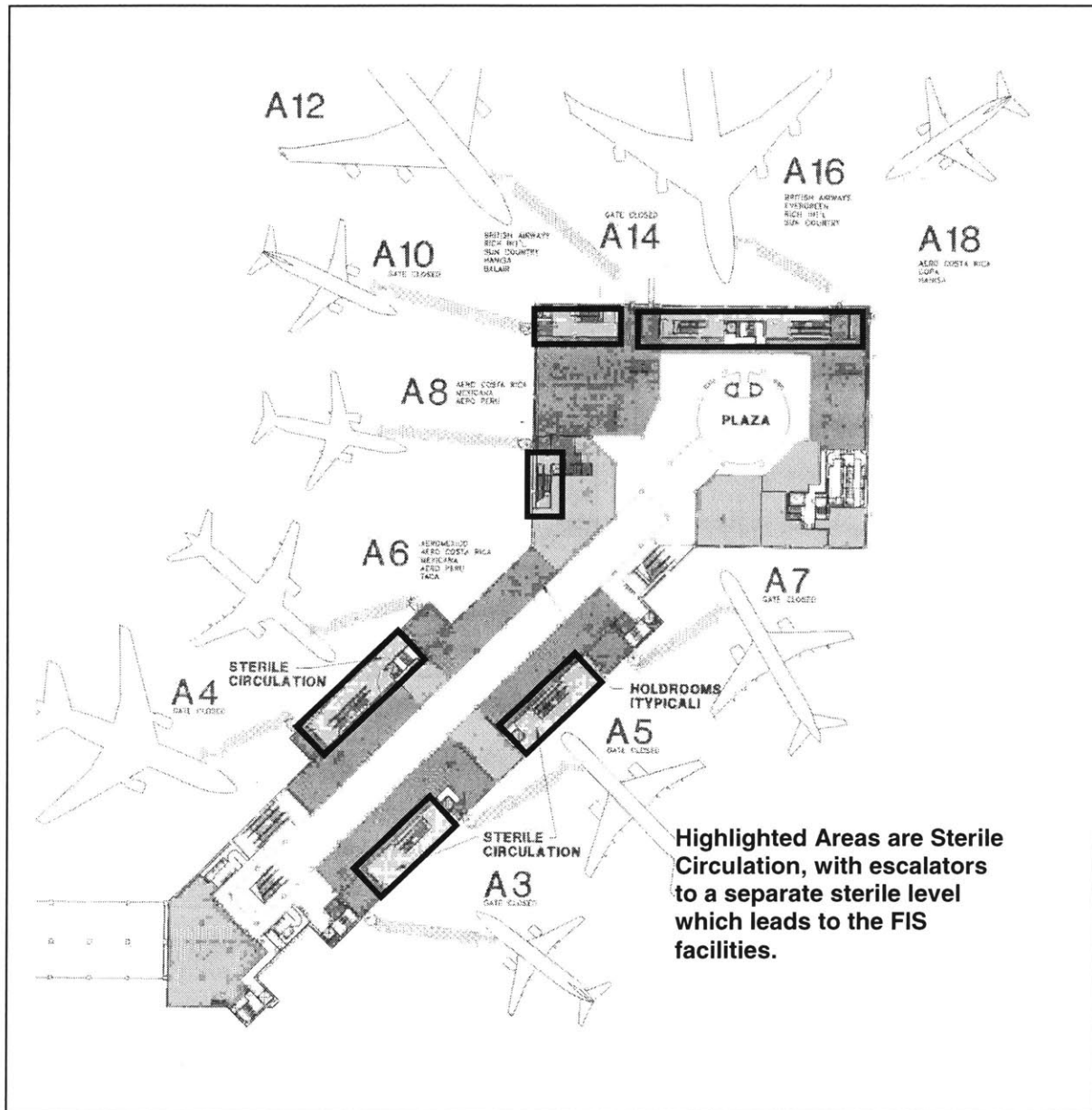


Figure 2.17: Miami / International Swing Gates, Concourse A

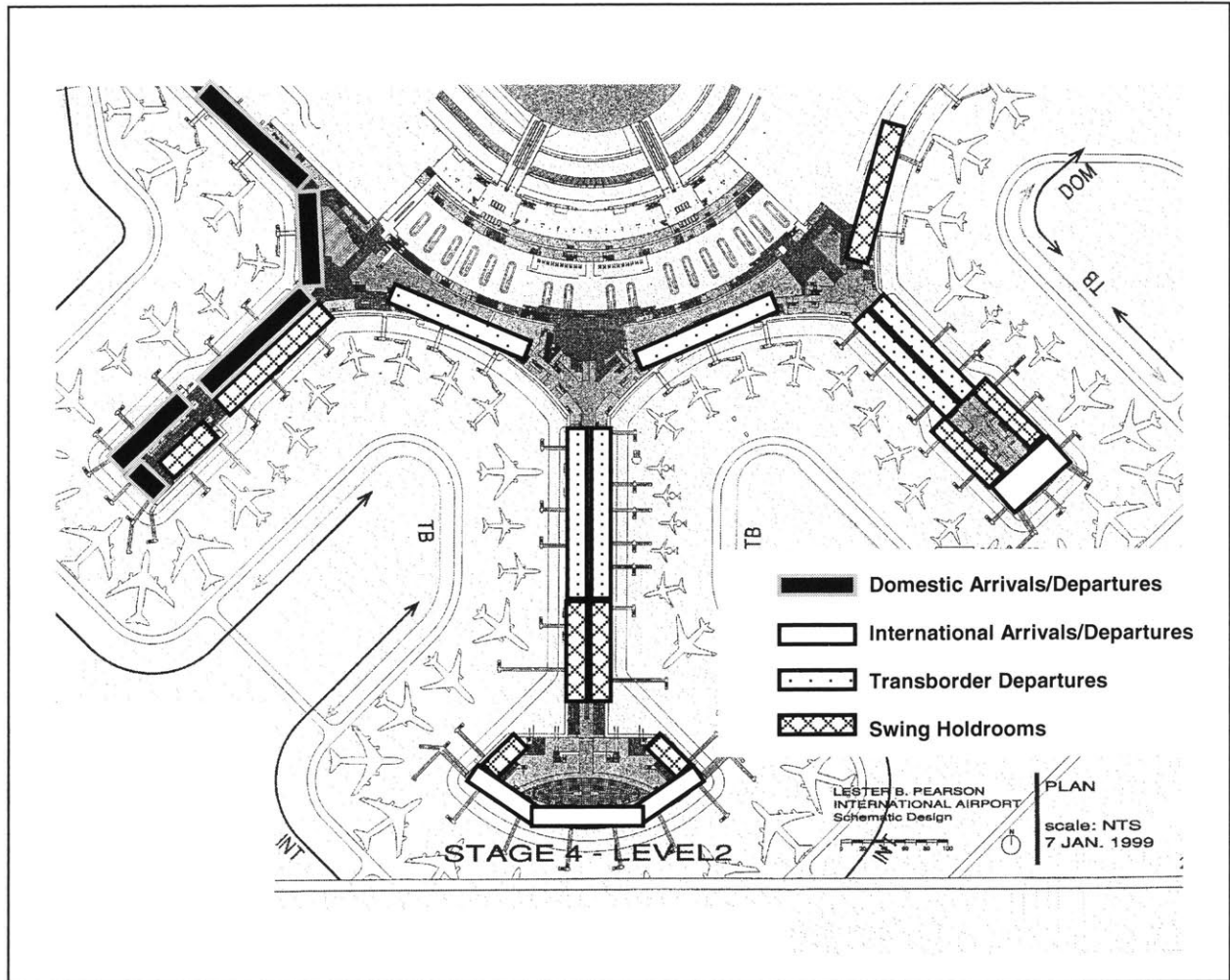


Figure 2.18. Plan for Toronto/Pearson at Full Build-out

the new passenger building development in Mombasa, Kenya – international flights were generally very early in the morning, while domestic flights were later in the day. Allowing for shared of facilities during the complementary sector's off-peak period provides part of the motivation for swing gates.

In addition, swing gates allow airlines to improve the utilization of their resources in an international-domestic hubbing scenario. Swing use of facilities allow for “swing aircraft designation” from international to domestic, and vice versa, eliminating the need to waste time and resources towing aircraft between an international-only and a domestic-only terminal. Figures 2.19 and 2.20 show this. In the era of international airline alliances, having the ability to operate aircraft both internationally and domestically with minimum ground-related operating costs is of value to airline partners because it provides them with more flexibility in fleet and crew schedule optimization.

There is both an operations cost and an opportunity cost associated with transferring passengers and aircraft between separated facilities. As the taxiing costs and the opportunity costs of aircraft and crew inavailability have been estimated at about US \$100 per minute, the value of serving international and domestic flights from a single gate can be quite substantial (Dada and Wirasinghe, 1994).

For the case of improving resource utilization, the flexibility provided by swing gates allows airlines to avoid the operating and opportunity costs associated with towing aircraft and transferring passengers between international and domestic buildings. The value depends on the frequency with which international-in-domestic-out moves will be made. The annual value could be expressed as follows (note that different assumptions on the value of each factor will yield different final results):

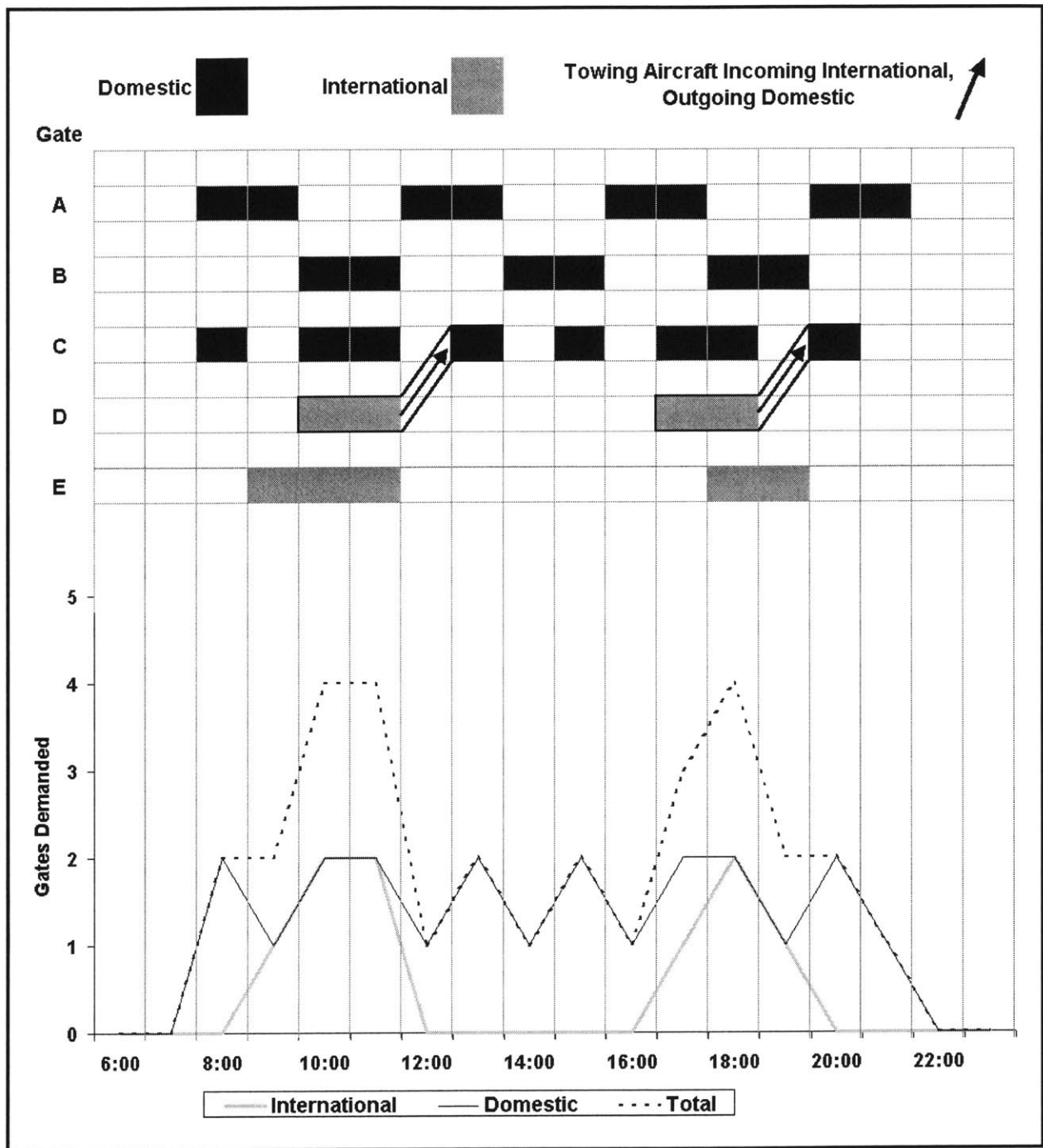


Figure 2.19. Towing Aircraft Required without Swing Gates

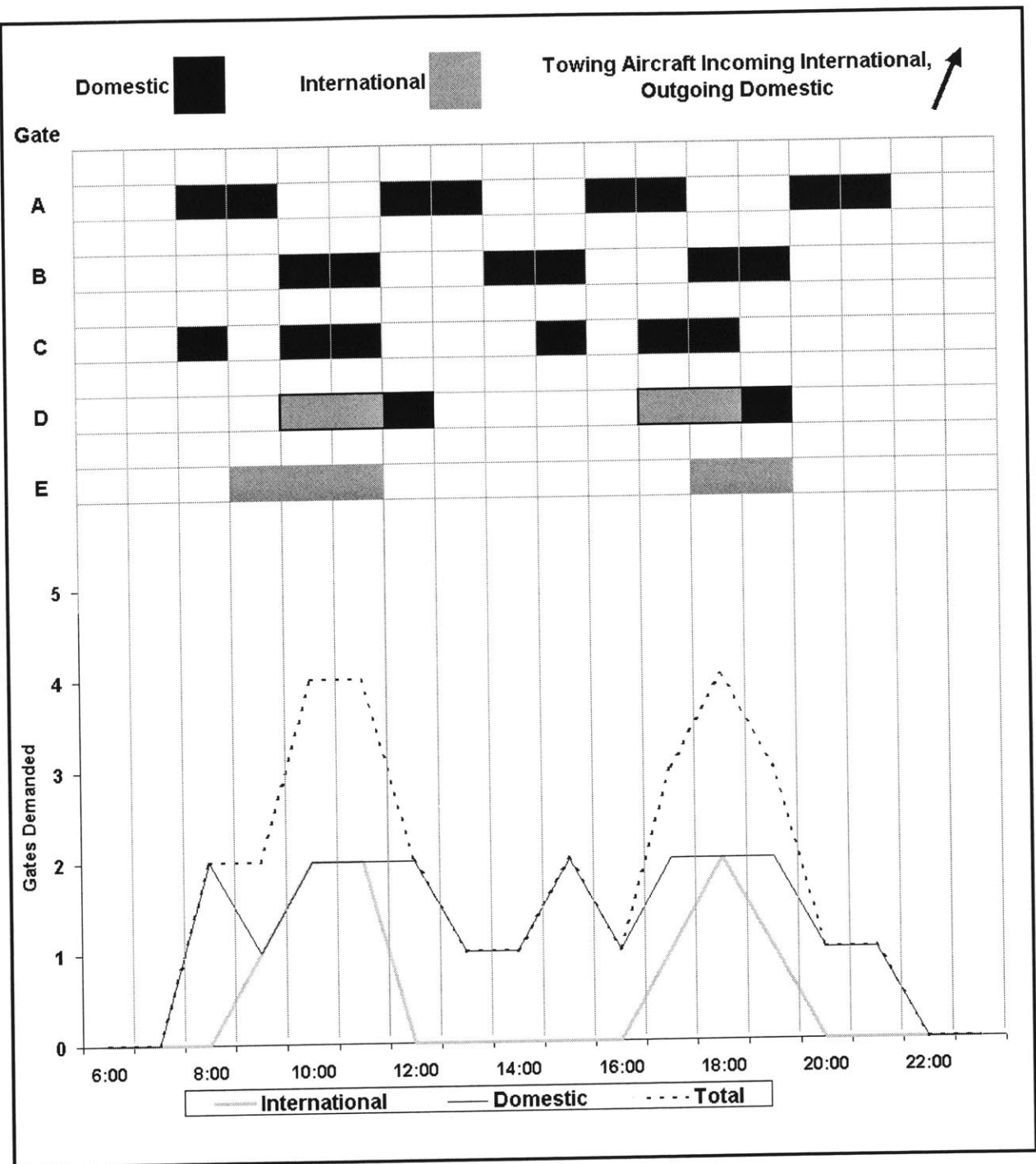


Figure 2.20. Towing Not Required With Swing Gates

$$\underbrace{\left(\left[\begin{matrix} \text{Minutes} \\ \text{Towing} \end{matrix} \right] \left[\begin{matrix} \text{Operating} \\ \text{Cost per} \\ \text{Minute} \end{matrix} \right] + \left[\begin{matrix} \text{Opportunity} \\ \text{Cost per} \\ \text{Minute} \end{matrix} \right] \right)}_{\text{Aircraft Costs}} + \underbrace{\left(\left[\begin{matrix} \$\$ \text{ per} \\ \text{pax-} \\ \text{minute} \end{matrix} \right] \left[\begin{matrix} \text{Minutes} \\ \text{Transferring} \end{matrix} \right] \left[\begin{matrix} \text{Avg. \#} \\ \text{pax per} \\ \text{aircraft} \end{matrix} \right] \right)}_{\text{Passenger Costs}} \left(\left[\begin{matrix} \text{Average} \\ \text{Weekly} \\ \text{Freq.} \end{matrix} \right] \left[\begin{matrix} 52 \text{ weeks} \\ \text{per year} \end{matrix} \right] \right)$$

Here, sample numbers are selected for the values above.

$$\left(\left[\begin{matrix} 15 \\ \text{Minutes} \end{matrix} \right] \left[\begin{matrix} \$25 \\ \text{per} \\ \text{Minute} \end{matrix} \right] + \left[\begin{matrix} \$75 \\ \text{per} \\ \text{Minute} \end{matrix} \right] \right) + \left(\left[\begin{matrix} \$0.16 \\ \text{per} \\ \text{pax-min.} \end{matrix} \right] \left[\begin{matrix} 10 \\ \text{Minutes} \end{matrix} \right] \left[\begin{matrix} 200 \text{ pax} \\ \text{per} \\ \text{aircraft} \end{matrix} \right] \right) \left(\left[\begin{matrix} \text{Average} \\ \text{Weekly} \\ \text{Freq.} \end{matrix} \right] \left[\begin{matrix} 52 \text{ weeks} \\ \text{per year} \end{matrix} \right] \right)$$

This equals approximately \$100,000 annually for every weekly international-domestic transfer avoided from the use of swing gates. The driving force to the benefits is the frequency at which these moves are made.

Separate international and domestic buildings lead to inefficient and costly use of space and resources. Prior to 1995 at Los Angeles/ International (LAX), United Airlines arriving international passengers deplaned or were bussed to the Tom Bradley International Terminal (TBIT). Passengers connecting to domestic flights proceeded through Immigration and Customs and then had to take a bus to United's domestic building. When TBIT was at capacity and LAX needed more international processing capacity, United built a Federal Inspection Services facility in the basement of its "domestic" building, with a glass-enclosed swing gate system to segregate the new international traffic from the domestic. As a result, United was able to eliminate the

need for passengers to transfer between buildings for international-to-domestic moves (LA Times, 1996). Another airline has since expressed interest in the same sort of swing gate setup for its domestic building. If at an airport with separate international and domestic buildings the same aircraft is to be used for a domestic flight, it too has to be towed to the domestic building, as is the case for airlines at Chicago/O'Hare.

The new environment of cost-effectiveness, increased volatility, and international airline alliances makes shared international and domestic facilities more viable and valuable. Some recent and planned passenger buildings have been designed with swing gates, including Atlanta/Hartsfield; Dallas/Fort Worth; Miami/International; Las Vegas/McCarran; Los Angeles/International; Orlando/International; Orlando/Sanford; Toronto/Pearson; Kuala Lumpur, Malaysia; Cairo, Egypt; Wellington, New Zealand; and Mombasa, Kenya; among others. See Appendix II for details on these and other cases.

One of the earliest examples of international/domestic swing gates is the Euro-hub facility at Birmingham (U.K.) International jointly developed by the airport and British Airways, which opened in 1991.

Extreme flexibility is the order of the day; any gate may serve as an international or a domestic gate; and the internal divisions can be reconfigured relatively easily. In this way, the company hopes to cope with whatever requirements emerge after 1992. (Woolley, 1990)

Another example of this is the planned Multi-User Integrated Terminal (MUIT) for Adelaide, Australia (2001). The Australian planners state clearly their perception of the benefits of combined international / domestic buildings.

The South Australian Government views the upgrading and integration of the domestic and international passenger terminals at Adelaide Airport as a fundamental component for the state's economic development, to re-position the Adelaide Airport infrastructure to international standards and provide an appropriate gateway image for South Australia.... The integrated terminal facility will be purposely built for the current and emerging aviation environment wherein international, domestic and regional services are closely integrated and airlines strive to make seamless transfers between the three levels the norm. The use of swing gates will further

accentuate the 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. The MUIT will be a state of the art terminal coordinated by the one operator, allowing efficiencies of operation and consistency in service and will be the first of its kind in Australia. As such, Adelaide Airport has the opportunity to be used as the model for future airport design in Australia. (South Australian Government, Office of the Premier, 1998)

2.3.4 Calculation: Example Spreadsheet for Determining Number of Shared Gates

A simple spreadsheet model illustrates how to determine the number of gates to share based on facility utilization requirements. Any benefits accrued from eliminating taxiing costs through swing “aircraft designation” would be in addition to the cost reductions determined here.

Suppose the peaks for user A and user B do not coincide. With exclusive use gates, only the designated user can use the gate. With shared use gates, both users can use the gate. These gates must be specially designed to overcome whatever constraints exist depending on the types of users (airlines, aircraft size, international / domestic, etc.). Figure 2.21 depicts a spreadsheet with the hourly demand for gates by each user. As in the departure lounge example, with exclusive use each user’s maximum demand is summed to determine the total number of gates needed. For shared use, the time period with the maximum demand (the “merged” schedule, summed over both users) determines how many gates are needed in all. The reduction in required gate positions is the difference between the number of gates required under exclusive use versus shared use.

Figures 2.22 and 2.23 present Gantt charts showing the gate assignments of the users’ flights in the spreadsheet under exclusive and shared use, respectively, along with graphs of each user’s hourly demand throughout the day. Figure 2.23 shows how sharing reduces the total capacity required from five to three gates – in the shared scenario, gates 4 and 5 are not needed to serve the given demand.

Time (hr.)	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	MAX
User A	0	1	2	3	2	1	1	2	2	2	1	2	3	2	2	1	0	0	3
User B	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	2
																			5
Total (Merged Schedule)	2	3	2	3	2	1	1	2	2	2	1	2	3	2	2	2	2	1	3

Figure 2.21. Spreadsheet Showing Hourly Gate Demand by User

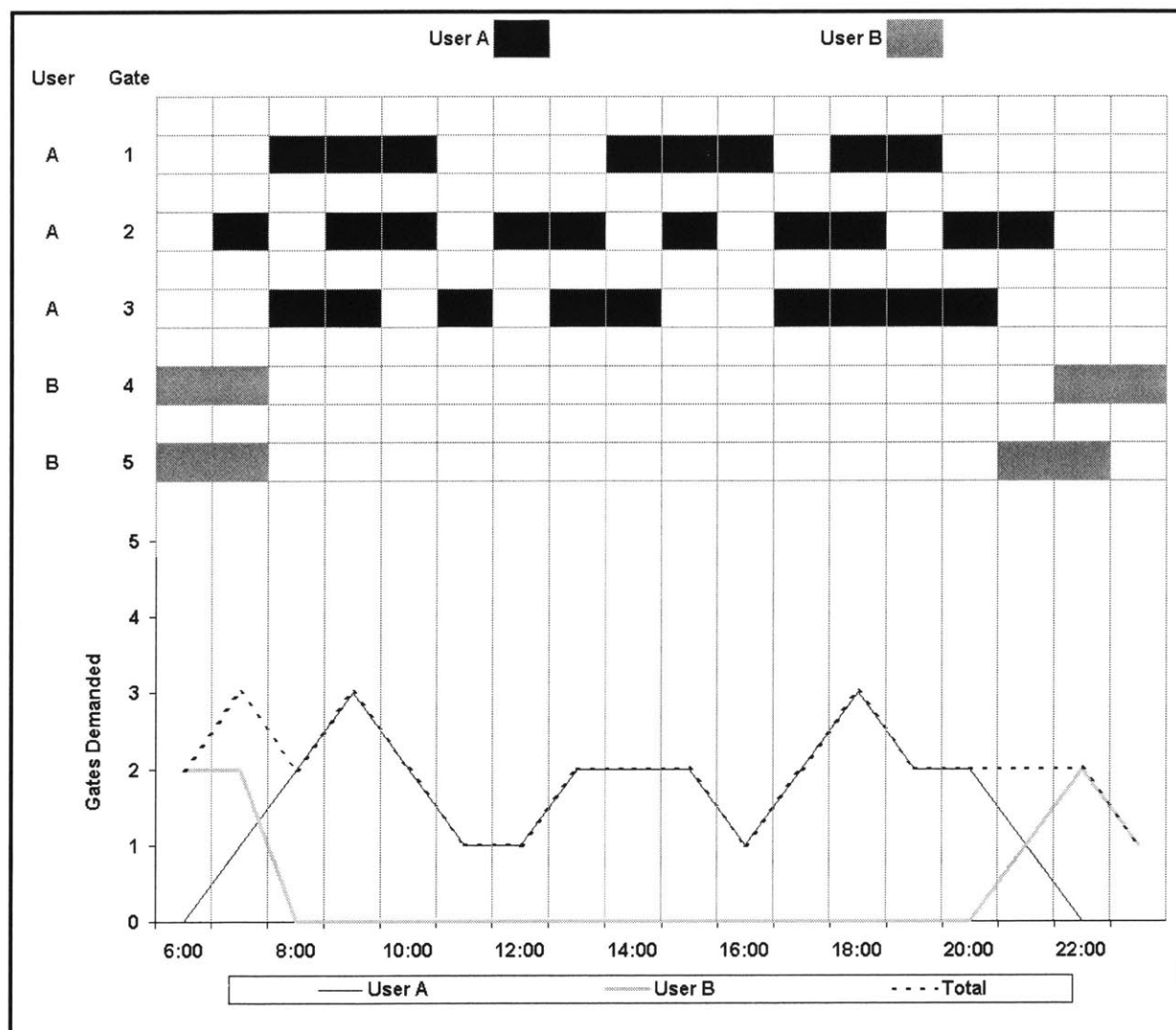


Figure 2.22. Gates Serve only One Type of User

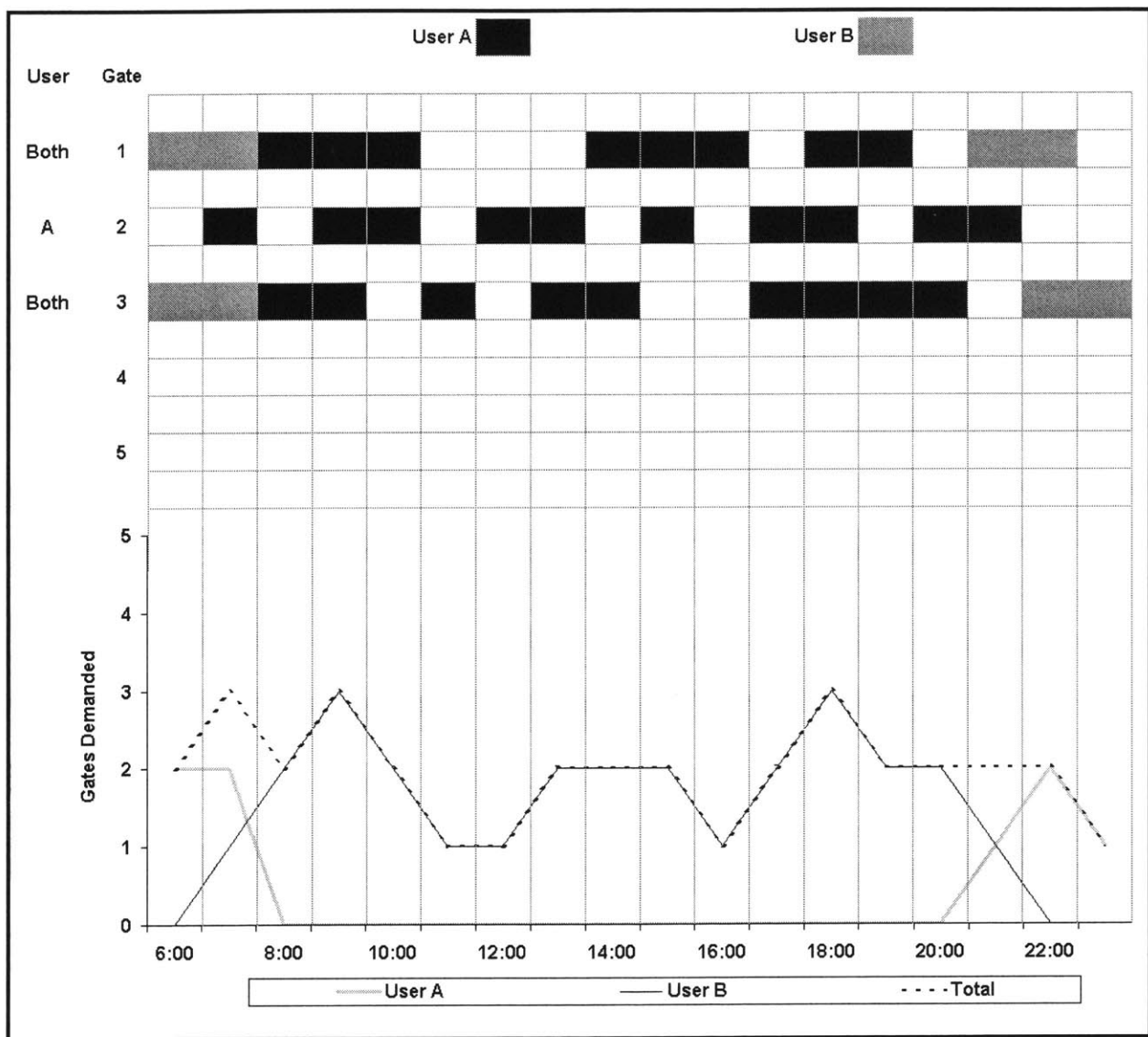


Figure 2.23. Multifunctional Gates Can Serve Both Users

These results could be obtained by making all the gates shared use. However, the best design will capture all of the potential benefits of overlapping peak demands at the least cost. The net benefits of shared gates will be maximized when the fewest of these can be used to achieve the potential gate savings, because each shared use gate comes with the additional cost of being built to accommodate both users. The remaining gates will be dedicated to each. Each airline has a base amount of dedicated use gates, but can dip into the pool of shared gates during its peak. This can be seen in Figure 2.23, where only two of the gates need to be designed for both users in order to achieve the savings.

The minimum number of shared gates needed is exactly equal to the reduction in gates required. This makes sense intuitively, as the reduction in gates is made possible because the gates are available to both aircraft types. The number of dedicated A gates is then equal to the difference between the maximum number of A gates demanded and the number of shared-use gates. Similarly, the number of dedicated B gates is equal to the difference between the maximum demand for B gates and the number of shared-use gates. The relationships below summarize the calculations of space reduction due to overlapping of peaks. Figures 2.24 and 2.25 provide graphic depictions of how the the demand profiles can be overlap resulting in lower total space requirements.

t = time period (e.g. hours)

A_t = User A demand at t

B_t = User B demand at t

A = Exclusive capacity for User A, No Sharing = $\max_t (A_t)$

B	=	Exclusive capacity for User B, No Sharing	=	$\max_t (B_t)$
T	=	Total Capacity Required, No Sharing	=	A + B
T'	=	Total Capacity Required, Sharing	=	$\max_t (A_t + B_t)$
R	=	Reduction in Total Capacity	=	T - T'
S	=	Amount of Shared Capacity	=	R
A'	=	Dedicated User A Capacity, Sharing	=	A - S
B'	=	Dedicated User B Capacity, Sharing	=	B - S

The value of flexibility is thus the unit cost of capacity (e.g. construction cost per gate) times the reduction in total capacity required. Since the amount of shared capacity, S, is the minimum required to obtain the potential savings, this is the optimal amount of shared capacity. The benefit of reduced total capacity would then be traded off with the cost of providing multifunctionality (for example, cost of CUTE or swing gate-sterile corridor system).

This chapter demonstrates the potential space and cost savings resulting from the shared use of space and facilities and how to determine how much to share. The benefit of sharing facilities is the space and cost savings it provides. However, if the actual arrival or departure times vary from the schedule, the time period each user requires space will change. This may affect the degree to which savings can be achieved from overlapping categories with peaks that do not coincide. The next chapter discusses the effects of these short term uncertainties and how they relate to shared use facilities.

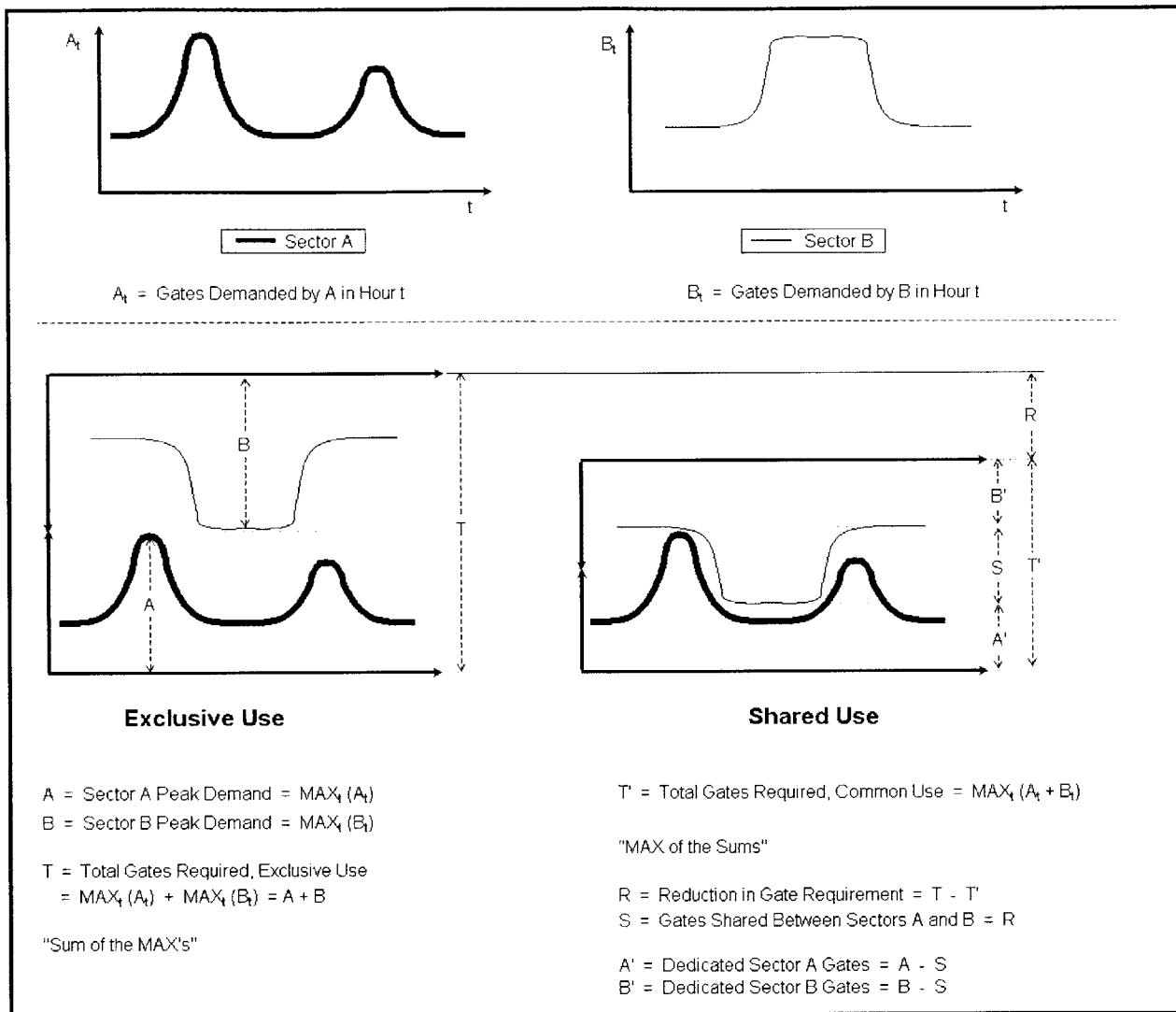


Figure 2.24. Graphical Depiction of How to Select Number of Shared Gates

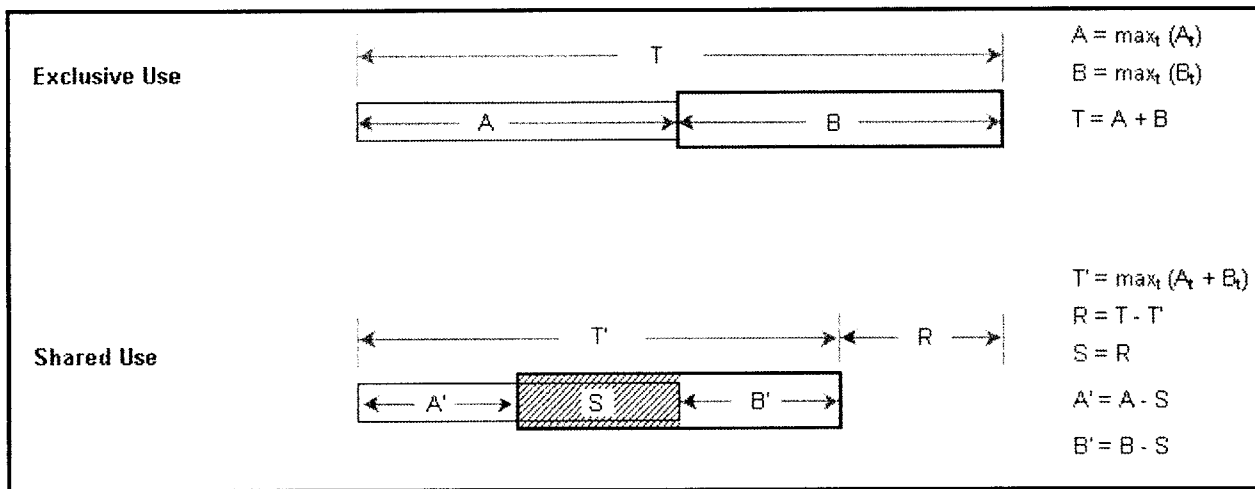


Figure 2.25. Another Graphical Depiction of How to Select Number of Shared Gates

Chapter 3. Schedule Uncertainty: Providing Insurance Against the Risk of Delays

This chapter expands on the last by recognizing the effects of schedule uncertainty on capacity requirements. Delays from scheduled arrival and departure times necessitate the provision of spare capacity. However, this spare capacity can be expensive in terms of cost per operation because it is not used very often. Designing spare facilities to be multifunctional allows them to be shared between different categories of users, decreasing the total amount that needs to be provided.

3.1 Spare Capacity

Chapter 3 shows that the total space required for passenger buildings can be reduced through the sharing of facilities. Shared use of space allows facilities to be allocated to the users who need them at a particular time. This is especially useful when there are peaks in scheduled traffic demand, because the peaks of one user can fill in for the valleys of another and vice versa. However, the previous discussion was based on scheduled flight arrival and departure times. In reality, flights are often delayed in their arrival and departure, increasing the demand for facilities. Tables 3.1 and 3.2 show flight departure and arrival on-time percentages by time of day for 10 U.S. airports between January 1998 and December 1999. An arrival or departure is considered on-time if it is within 15 minutes of the scheduled time. Two observations are important: 1) On average, only about 80 percent of flights depart and arrive within 15 minutes of their scheduled times. 2) Delays worsen throughout the operating day, but recover at night.

Several factors act to cause delays – including congestion at the airport, air traffic control ground-holding policies, and adverse weather conditions locally or in other parts of the country – which can make actual levels of demand higher or lower than scheduled levels throughout the

Table 3.1. Percent of All Carriers Reported Flight Operations Departing On-Time

Airport	Hour of Day																		Avg
	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	
Atlanta/Hartsfield	92	90	88	82	82	83	87	87	80	78	75	71	76	73	75	76	78	78	81
Boston/Logan	93	91	89	92	88	89	86	88	86	80	81	78	72	76	75	73	---	93	84
Chicago/O'Hare	87	87	80	79	81	77	76	75	67	70	68	66	65	66	65	68	69	90	74
Dallas/Fort Worth	93	93	88	84	83	80	84	88	80	83	84	80	79	83	80	86	86	77	84
Los Angeles/Int'l	91	93	85	83	77	78	79	77	79	76	80	77	79	74	76	79	90	90	81
Miami/Int'l	96	90	87	92	89	88	81	83	75	77	75	75	77	80	75	100	---	87	84
New York/Newark	92	93	90	87	85	90	85	86	79	75	69	63	63	61	60	63	72	97	78
New York/La Guardia	94	92	90	87	81	85	87	84	81	85	83	76	70	71	68	83	---	97	83
San Francisco/Int'l	94	93	90	88	85	84	81	83	84	84	81	88	78	83	82	83	88	93	86
Washington/National	94	92	90	88	88	84	90	87	89	90	85	88	81	79	81	91	---	---	87
Avg.	93	91	88	86	84	84	84	84	80	80	78	76	74	74	74	80	81	89	82

Source: U.S. DOT Office of Aviation Enforcement and Proceedings, www.dot.gov/airconsumer, CY1999

Table 3.2. Percent of All Carriers Reported Flight Operations Arriving On-Time

Airport	Hour of Day																		Avg
	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	
Atlanta/Hartsfield	71	86	83	76	83	81	81	82	76	73	64	70	68	67	67	64	70	73	74
Boston/Logan	83	85	92	86	91	81	84	84	85	82	78	74	74	64	69	72	74	78	80
Chicago/O'Hare	76	85	77	78	78	71	69	70	66	67	63	64	61	61	57	67	68	76	70
Dallas/Fort Worth	86	88	87	83	83	84	88	82	83	86	84	84	81	79	77	80	77	83	83
Los Angeles/Int'l	96	92	86	84	86	80	80	81	80	80	79	80	80	79	79	78	79	80	82
Miami/Int'l	47	94	90	88	85	82	76	73	83	75	76	71	71	71	67	68	70	69	75
New York/Newark	73	82	88	89	86	86	90	75	73	62	55	65	52	51	56	62	67	76	72
New York/La Guardia	76	86	85	82	83	79	81	79	80	74	74	67	63	63	67	73	74	79	76
San Francisco/Int'l	82	93	92	86	85	83	77	84	82	81	85	82	82	86	82	80	76	82	83
Washington/National	---	92	81	82	82	84	85	84	84	85	81	79	76	76	82	76	71	80	81
Avg.	77	88	86	83	84	81	81	79	79	77	74	73	71	70	70	72	73	78	78

Source: U.S. DOT Office of Aviation Enforcement and Proceedings, www.dot.gov/airconsumer, CY1999

day. This schedule uncertainty affects the amount of space savings that can be achieved through shared space or gates – there is a certain degree of uncertainty as to when peaks will occur and how large they will be on any given day. For instance, a string of delays at the beginning of a peak period could serve to amplify the peak, as seen in the example in Figure 3.1. When a flight is delayed, the gate it occupies does not become available to the next flight for which it is scheduled, which could result in delay to another flight waiting to use that gate. Delays can lead to even more delays downstream. The costs of delay, including aircraft inavailability, passenger inconvenience, and additional crew and fuel costs, can be very large.

Since the demand throughout the day is not certain, some spare capacity should be provided beyond the minimum amount as insurance to cover these variations from the schedule. Spare capacity can be thought of as a form of insurance – it allows airport and airline operations managers to cover the risks (and costs) associated with unexpected variations from scheduled activity. Figure 3.2 illustrates how spare capacity provides “breathing room” when the possibility of delays introduce uncertainty in scheduled demand. In practice, airlines recognize this need for spare capacity and include it implicitly in their calculation of gates requirements to accommodate a given flight schedule.

Because it may not be needed very often the spare capacity could be provided in a relatively inexpensive form. This is the idea as an overflow parking lot, made inexpensively of gravel or simply grass and used to relieve the main paved lot during peak times. It would be expensive per “parker” to pave overflow parking at a shopping mall if it is only used during the Christmas shopping season. Similarly, remote gate stands cost much less than providing a dedicated gate in the passenger building that will not see much use.

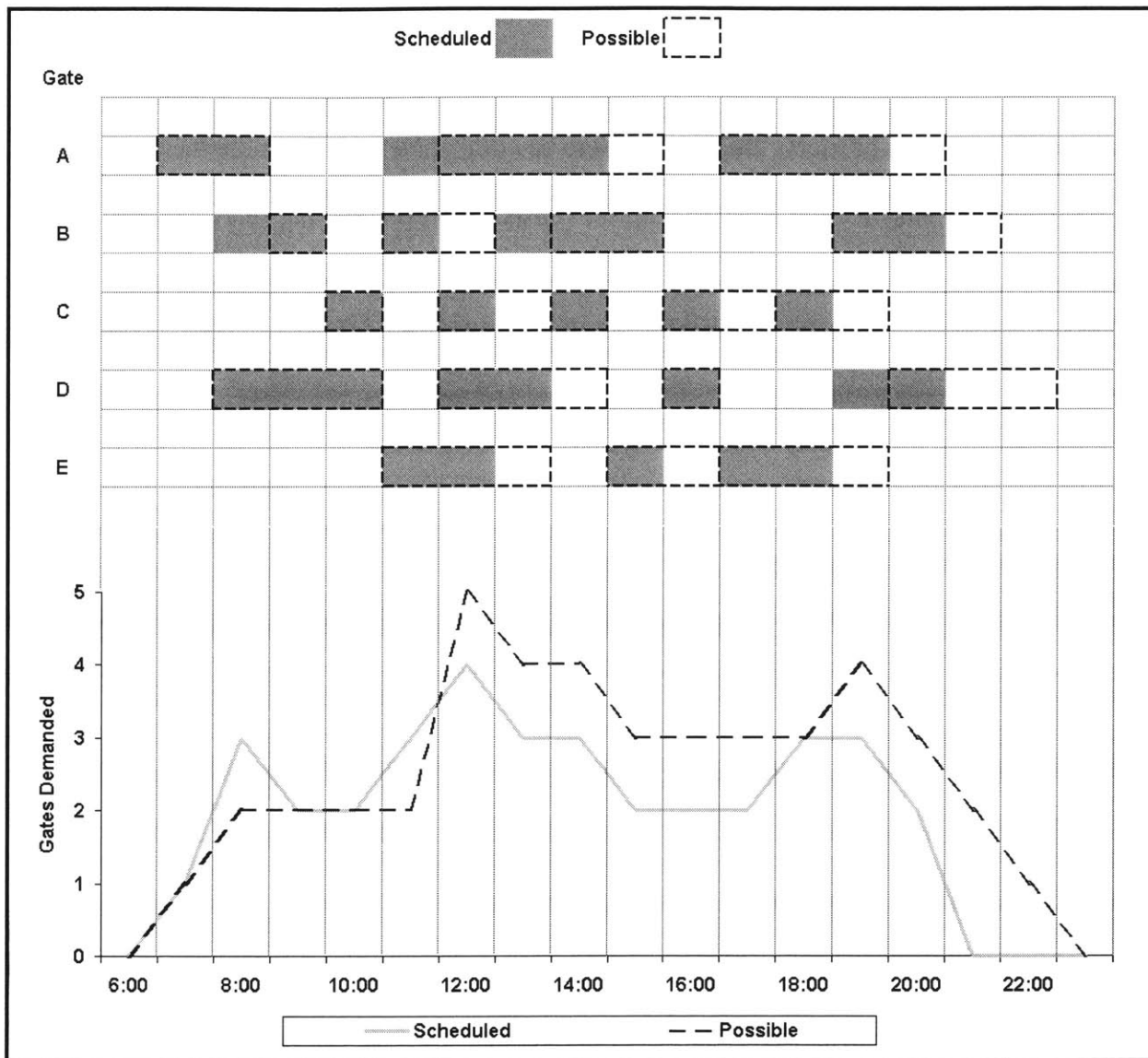


Figure 3.1. Effect of Delays on Peak Demand

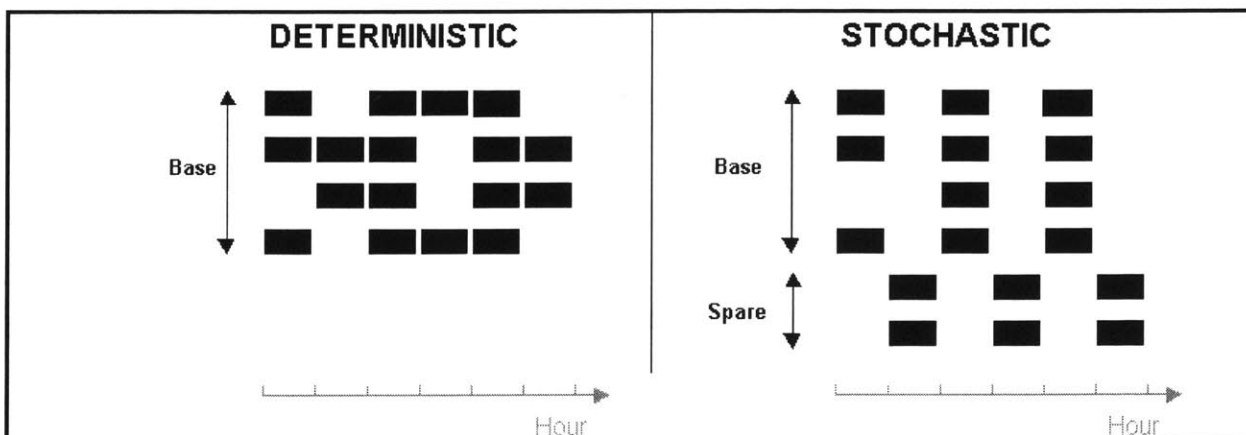


Figure 3.2. Spare Capacity Provides "Breathing Room" in Operations

More importantly, spare capacity which is shared between more than one category of users is more valuable in the face of schedule delays, precisely because it simultaneously provides insurance to several types of users. Building gates to be compatible between more than one user (i.e., multifunctional) may require additional upfront costs. However, sharing spare capacity between users will increase its utilization, making it less costly per operation than if it were exclusive to a single user. The total number of spare gates required will be reduced, as total gates were reduced with overlapping peaks in Chapter 2.

3.2 Calculation of Spare Capacity

Horonjeff and McKelvey (1994) observe that airlines typically schedule gates for occupancy between 50 and 80 percent of the operating day, which they refer to as the gate utilization factor. In planning the total gate requirement for a given scheduled demand, they recommend this utilization rate be applied by simply dividing the schedule gate requirement by the gate utilization factor to provide the necessary spare capacity. However, since the observed gate utilization partially results from peaking as described in Chapter 2, this calculation overestimates the spare capacity needed to cover uncertainty in arrival and departure times. Designers and planners need a way to estimate how much spare capacity to provide to mitigate the effects of schedule uncertainty.

Bandara and Wirasinghe (1988) replace Horonjeff and McKelvey's assumption on the gate utilization factor with a separation time around the scheduled gate occupancy times, accounting for the time needed for the aircraft to push-out, clear the apron, and allow the next aircraft to move into the gate from the apron. The aircraft arrival rate, gate occupancy time, and

separation time are then modeled as random variables, from which the number of gates necessary to provide a given probability of zero ground delay to aircraft requiring gates can be determined. Hassounah and Steuart (1993) update Steuart's original 1974 work, estimating the required number of gates under uncertain demand conditions. Stochasticity in both arrival and departure times results in uncertainty in the actual time any given flight will occupy a gate. Figure 3.3 represents this as a probability distribution of a flights' gate occupancy time. The important feature is that every flight has the possibility of occupying its gate for a wider time period than it is scheduled for, which was also apparent in Figure 3.1. The net result, shown in Figure 3.4, is that the actual demand throughout the has the potential of being somewhat higher than the scheduled level – as shown by the difference between the discrete “steps” representing the scheduled demand and the smooth curve representing the sum of each flight's probability distribution from Figure 3.3. This model is used to determine the number of gates necessary to ensure a given probability that the demand for gates does not exceed the supply. The gates beyond that needed by the scheduled demand represent the spare capacity. It is assumed that one standard deviation beyond the expected (scheduled) gate requirement is sufficient. de Neufville (1976) suggests a rule-of-thumb for the number of spare gates based on this finding. If the distribution can be reasonably approximated to be Poisson, the total number of gates needed is the sum of the number of gates required by the schedule plus the square root of the number of gates required by the schedule, because the variance of the Poisson distribution is equal to the mean:

$$\text{Total Gates Required} = (\text{Gates Needed by Schedule}) + \sqrt{(\text{Gates Needed by Schedule})} \quad (4)$$

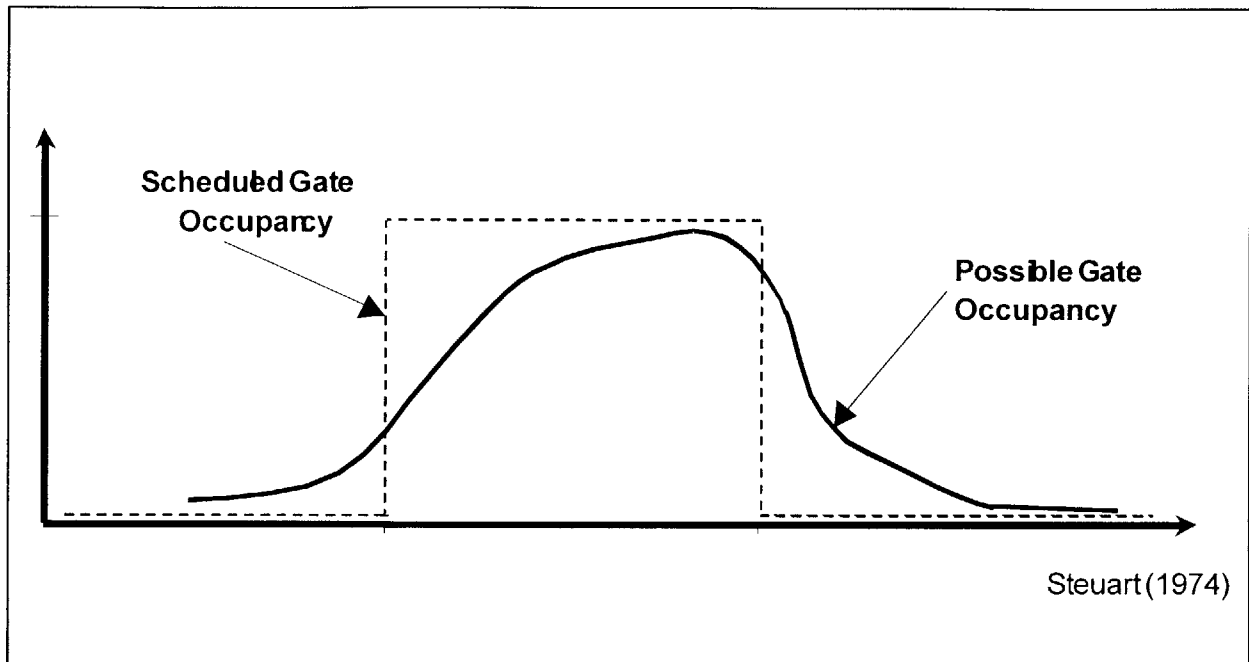


Figure 3.3. Probability an Individual Flight is Occupying its Gate

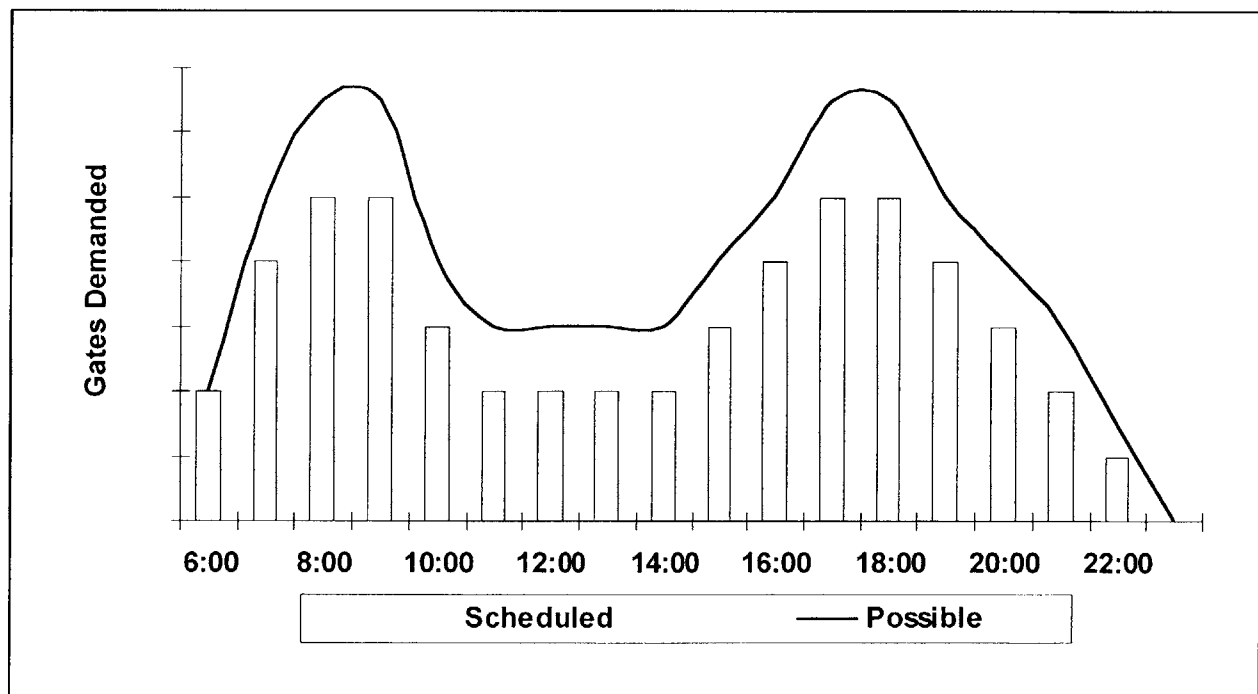


Figure 3.4. Possible versus Scheduled Demand for Gates Throughout the Day

The second term – the standard deviation, which represents the spare capacity – decreases relative to total capacity as the number of gates needed by the schedule increases. In other words, larger scale operations require less spare capacity as a percentage of total capacity.

Spare capacity which is multifunctional is more valuable in the face of schedule delays precisely because it simultaneously covers delays for several users. Fewer total spare gates are needed than if each individual operation has its own spare capacity. For example, if two users both require 25 gates by their schedule, under exclusive use of spare capacity each would require five gates for a total of 10 spare gates. However, if the two users shared the spare gates, they would only require seven gates between them, a savings of three gates.

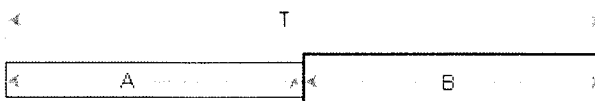
Sharing is used to reduce facilities requirements in the case of both peaking and schedule uncertainty. The amount of sharing required for peaking is estimated according to the procedure for the deterministic case in section 2.3.4. The additional sharing of spare capacity for stochastic demand is then $\sqrt{A'+S+B'}$. The reduction in spare capacity is the difference between this and that required if each user has its own spare capacity, $\sqrt{A'} + \sqrt{S} + \sqrt{B'}$. The value of multifunctional spare capacity is this difference times the unit cost of the spare capacity.

Figure 3.5 shows the combined effect of sharing gates when there is both peaking and uncertainty in scheduled arrival and departure times. The first portion of the figure shows the savings resulting from overlapping peak / off-peak demands, as presented in Chapter 2. This analysis is unrealistic in that the demand is deterministic – everything goes exactly according to the schedule. In reality, externally-caused delays can make actual demand greater than scheduled, requiring that spare capacity be provided to cover this uncertainty. The second portion of the figure shows how much spare capacity is required if two users each have their own

PEAKING

DETERMINISTIC SCHEDULE

Exclusive Use

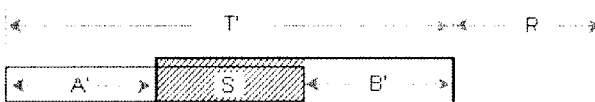


$$A = \max_t (A_t)$$

$$B = \max_t (B_t)$$

$$T = A + B$$

Shared Use



$$T' = \max_t (A_t + B_t)$$

$$R = T - T'$$

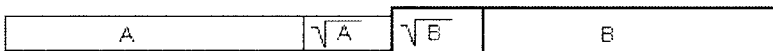
$$S = R$$

$$A' = A - S$$

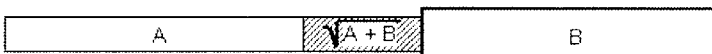
$$B' = B - S$$

SCHEDULE UNCERTAINTY

No Sharing of Spare

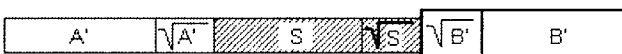


Sharing of Spare only



PEAKING & SCHEDULE UNCERTAINTY

Sharing, but not of Spare



Sharing, including Spare



Figure 3.5. Total Savings Resulting From Sharing Base and Spare Facilities

spare versus if they share the spare between them. The third portion of the figure combines the previous two considerations.

Spare capacity is a way to provide operations managers flexibility in allocating gates when there is uncertainty in flight arrival and departure times. Spare capacity which is multifunctional is more valuable because it will be more highly utilized. The next chapter moves from schedule uncertainty (delays) to future uncertainty and how the use of flexibility in design decisions today can improve utilization and reduce costs in the future.

Chapter 4. Future Uncertainty: Providing Insurance Against the Risk of Obsolescence

The previous chapters describe how multifunctional facilities can be shared between different categories of users to improve current operations. The benefits of higher utilization are achieved immediately in the form of lower total space requirements for new buildings, increased capacity for existing buildings, more cost-effective coverage of delays, and improved revenues. The focus of this chapter shifts from current operations to flexibility for future use and development. As the useful life of passenger buildings is around thirty to fifty years, planners must ensure the facilities they design today remain cost-effective in the future. This chapter presents a methodology for valuing the benefits of multifunctionality as a way to determine its optimal provision for future needs, assuming there is no existing benefit from overlap of daily or seasonal peaks.

Investing in a fixed facility with a long term life is risky – that is, it exposes the airport to potentially high redevelopment costs. The flexibility to reallocate capacity at low cost in the future can be viewed as a form of “insurance” to protect against this risk. Assume that total capacity is most cost-effectively expanded in discrete blocks (i.e., several gates at a time) by the procedures described in section 1.4.2. For a given total capacity level, providing the wrong mix of capacity (aircraft type, international / domestic, etc.) within each block leads to the need for either expensive renovation or early expansion in the future. The driver for this mistake is uncertainty in future demand. The planning process must identify different future demand scenarios given that there is both variability and the threat of major shifts in demand mix. The next step is to analyze the tradeoff between the costs and benefits of multifunctionality to determine its optimal portion of total facilities. The optimal multifunctionality minimizes the expected total cost of any capacity allocation decision with respect to the scenarios, where the

total cost is the sum of the costs of providing multifunctionality and the costs of future redevelopment if the traffic mix turns out different than expected. The analysis is intentionally approximate to avoid implying a false sense of precision in the valuation. Instead, the aim is to obtain ballpark estimates of how much potential cost can be avoided by providing flexibility, and then using these results to recommend how much flexibility is it worthwhile to include.

4.1 Forecasting Scenarios

Retrospective studies have shown that any forecast on the level of future demand will not be realized exactly, and therefore should not be the sole basis for planning. Instead of forecasting a single target for design, planners should consider a range of possible future outcomes and then design the passenger building to perform reasonably well under any of them.

Current practice is to make a single forecast of future traffic and to plan capacity to accommodate it. This practice is problematic because the future is too uncertain to be predicted accurately. Future population growth, economic activity, airline decisions, industry structure, technology, regulations, and policies – all of which heavily influence demand at an airport – can only be guessed at today. Forecasts of future demand are even less accurate when disaggregated into different categories – for example, international vs. domestic or wide body vs. narrow body jets (Bluestone, 1979). That so many influential factors might change underscores the need for flexible planning and design.

Both the absolute levels and the mix of traffic are uncertain. With respect to expandability, the optimal capacity staging decisions are a function of the uncertainty in absolute levels of traffic. However, multifunctionality is useful when the mix of traffic is uncertain. There are basically two types of forces driving this uncertainty – normal variability and major

shifts. Figure 4.1 shows this for international/domestic mix. The presence of both factors increases the potential for mis-design and high costs, and thus warrants the inclusion of at least some minimal amount of flexibility.

Scenario-based planning forces planners to recognize how variability and major events can influence the cost-effectiveness of a design, and then to develop design strategies to cost-effectively deal with such large future uncertainties. The conclusion is to design flexibility in up-front in the forms of expandability and multifunctionality. The optimal amount of flexibility depends on the cost of building this flexibility and on the range of possible scenarios, their likelihood, and their potential costs. The range of possible future scenarios depends on the extent of variability and the possibility for major shifts at a given airport.

4.1.1 Normal Variability in Traffic Mix

Past experience shows that at any airport, the traffic mix exhibits some variability. Any casual look at past traffic data shows that growth is typically not “straight” – it fluctuates slightly

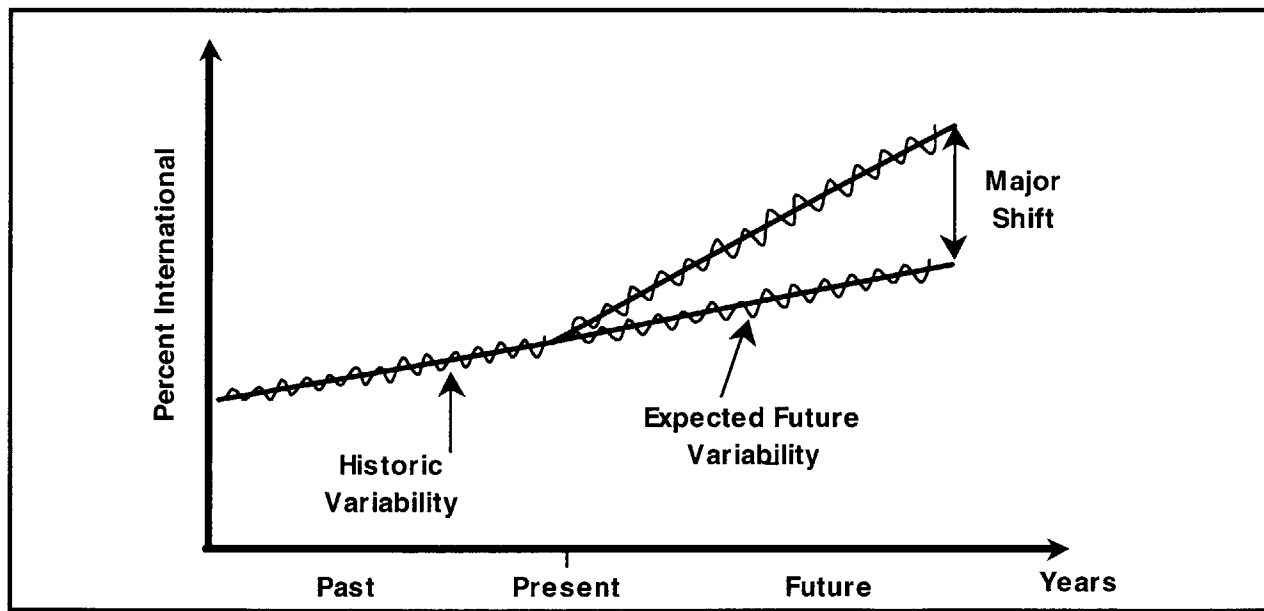


Figure 4.1. Variability versus Major Shift in International/Domestic Mix

about some long term trend. Individual airline's fleet assignment decisions may vary from year to year, affecting the aircraft mix. Business cycles of regional and international economies can affect the international/domestic mix.

The effects of wars and oil prices can tremendously impact international and domestic travel. For example, traffic dipped severely during the oil crisis of the 1970s and the Persian Gulf War in the early 1990s. Neither of these events were expected to happen, yet both greatly impacted demand at airports. That these and a myriad of other economic events could happen increases uncertainty. There is no reason to expect that the variability in mix will be less in the future than it has been historically at the airport. The historical fluctuation around the trend can therefore be used to identify the minimum range of possible future outcomes around any given forecast.

4.1.2 Major Shift in Traffic Mix

In addition to normal variability there exists the possibility of major shifts in demand patterns – fundamental changes which affect facility requirements. Major unexpected events have even larger impacts on future demand for passenger building capacity than annual variability. These can include changes in regional and international economies, the airline industry, technology, and regulations. While it can be difficult to think about all of the different factors that could affect traffic at an airport, this is the main risk airports face in providing and allocating a given amount of capacity among several users or functions.

Under deregulation, airline traffic is increasingly unpredictable. This increases the uncertainty in demand at passenger buildings. Airlines may choose to relocate hubbing operations to an airport, which would lead to more transfer traffic. Alternatively, the possibility

exists that an airline may move traffic to a competing hub or overfly an existing hub to provide direct service to a destination.

Technology is constantly changing. A changing aircraft mix can have significant effects on airport passenger building facility requirements, from gate positions to departure lounges. For example, there is uncertainty as to whether the New Large Aircraft (NLA) will ever be used, and if so, when and where. However, the possibility of its introduction has motivated some airports to design airfield and passenger building facilities with the capability of accommodating the new technology. Of course, the degree to which flexibility is provided to accommodate the NLA depends on the likelihood of its use at that airport.

Regulatory and policy changes can also affect facility requirements. For example, Hirsh (1995) details the effects of changes in immigration and customs inspection procedures which have made some FIS facilities inefficient and obsolete. The author recommends planning the facilities for flexibility, with the explicit goal of being able to deal with unforeseen regulatory changes.

One could imagine any number of possible scenarios above, or combinations of scenarios. The goal is to forecast the range of possible scenarios and their likelihood, and then inject enough flexibility to effectively respond to changes in the traffic mix through the reallocation of capacity.

4.2 Flexibility as Insurance

Flexibility can be thought of as a form of “insurance” against these risks, just as automobile insurance protects against the risk of potentially high costs if you get in a car accident (Bluestone, 1979). As in the case of insurance premiums, it is important to note that

flexibility generally costs much less than the potential costs of an unfavorable outcome. In passenger buildings, there is usually some upfront cost to designing in flexibility, which depending on the application is relatively small in comparison to the potential costs it is designed to protect against. However, extreme flexibility may not be warranted if there is only low or moderate uncertainty. The most cost-effective amount of flexibility to provide depends both on its price and the range of possible future scenarios which can result in increased renovation and expansion costs. Sections 4.3 and 4.4 detail methods for valuing the benefits of flexibility to future uncertainty and trading them off with the costs.

The concept of insurance implies a “reactive” or “defensive” use of flexibility to protect against potential costs of changes. Flexibility can also be used “proactively” or “offensively” to take advantage of new opportunities in a changing environment. The valuation procedure would be identical, except the value of flexibility would not come from minimizing potential costs, but instead by maximizing potential revenues.

4.2.1 Examples

Flexibility in the physical design allows for flexibility in the long term use and development, as facilities can easily be adapted to perform well under a range of loads and uses. The planning for the people-mover system at New York/Newark is an example of flexibility as insurance to an uncertain future. When the new passenger buildings were being planned in the early 1970s, planners realized that while present needs did not necessitate it, there might be a future need for an inter-terminal transportation system. They designed “notches” in the airside of the building’s structure to provide a right-of-way for a future people-mover system. During the construction of the original buildings contractors installed foundations for the future

guideway in the open space between them. Some upfront cost was required in the design of the building structure and the placement of additional foundations. However, this investment was very worthwhile, as high growth in the 1980s and 1990s made the automated people-mover system necessary. It was easy to implement because the original design made it possible, while the cost of the full commitment was delayed for more than a decade (Woodend, 1993).

4.2.2 Multifunctional Facilities

Multifunctionality provides similar insurance value, allowing space and facilities to be allocated to different users in the face of long term uncertainty in the future traffic mix.

Facilities built to serve a certain mix of traffic or operating practice will become functionally obsolete if the future ends up different than expected. There will be additional costs associated with remodeling or expanding the facilities in the future to serve the actual traffic needs.

Multifunctional facilities serve different uses, allowing them to accommodate change at little or no additional cost in the future. Figure 4.2 illustrates this. The space labeled S is multifunctional space that is currently shared between two different categories of users, A and B. This shared space can be allocated to whichever user experiences more growth in the future. If this space could not serve both users, the total capacity would have to be expanded to meet the future mix.

Gate positions that can be used by a variety of aircraft sizes provide flexibility to a changing future aircraft mix. The airside concourses at the new Denver/International are an example of a facility design allowing for adaptation to changing aircraft mix. According to designers, it was important to

...accommodate growth and change in terms of passengers served and quantity, size, and type of aircraft used by the airlines....The window wall is designed to allow for changes in gate location as aircraft gates can be placed anywhere along its length and be relocated as required. (Suehiro, McCagg, and Seracuse, 1992)

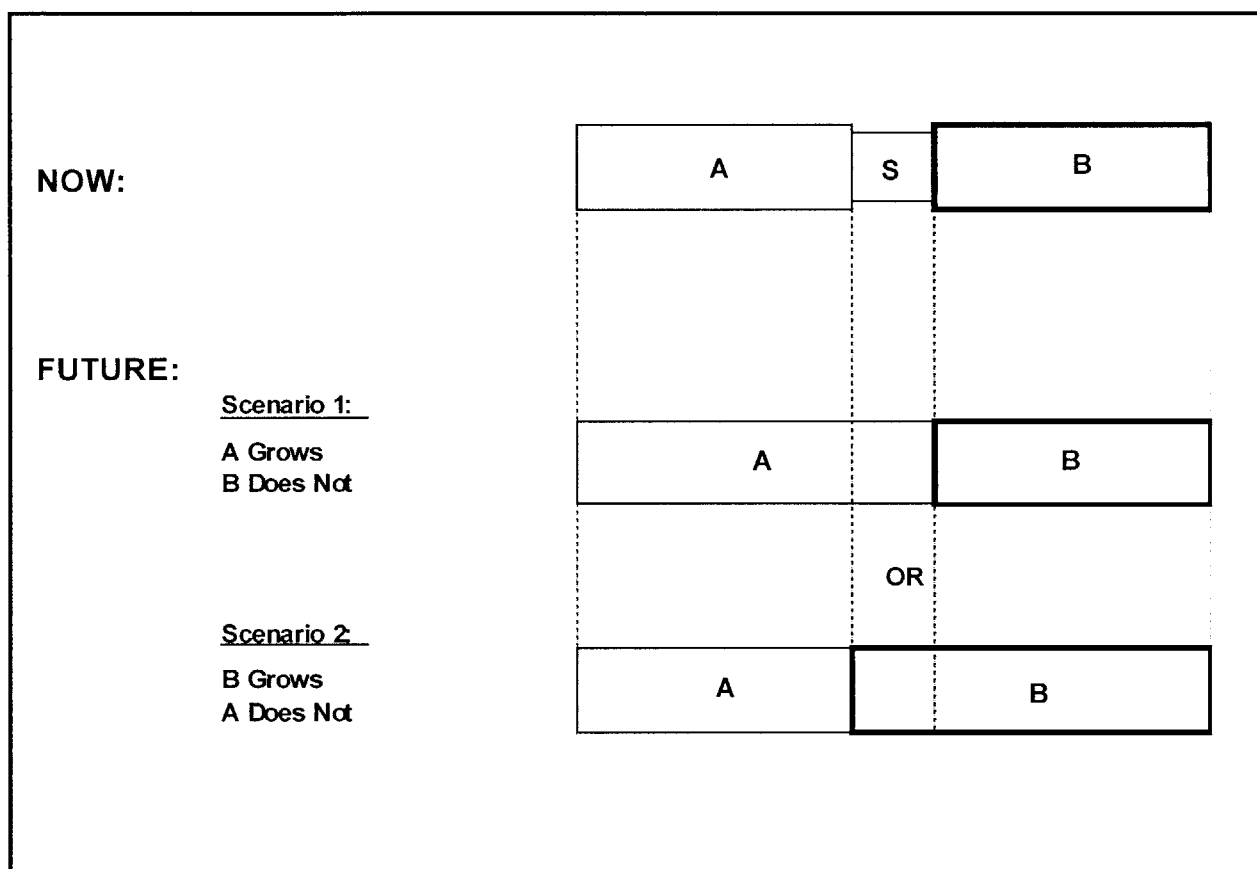


Figure 4.2. Multifunctional Facilities can be Reallocated to Meet Future Needs

A similar design concept was used for the new D Gates at Las Vegas/McCarran. Not only do the building, apron, and loading bridge have to be able to serve different size aircraft, the departure lounges must also be able to accommodate larger loads if the aircraft mix changes. Shared lounges can “absorb” changes in aircraft mix better than individual lounges. For instance, a lounge shared by two B757’s may be reallocated to one B747 at relatively little cost.

Likewise, the flexibility provided by CUTE systems allows facilities to be easily and inexpensively reallocated as airlines increase or decrease their presence at an airport. This protects against some of the costs of renovating interior space and information systems every time airlines change facilities.

International/domestic swing gates can be reallocated when the mix of traffic changes. The development of Washington/Baltimore (BWI) is a case in point. In the early 1990s both international and domestic traffic were growing rapidly at the airport. As part of the plan to increase capacity, the state and airport officials decided it was necessary to build a new international pier. However, after the decision to expand had been committed to, U.S. Airways unexpectedly moved much of its international traffic from the airport to Philadelphia/International (American Association of Airport Executives, 1993; Little, 1998). To make matters worse, the airports’ early attempts to attract international flights were unsuccessful. As a result, BWI’s new international pier – which opened to great architectural fanfare – has been criticized for being underutilized (Little, 1998).

At the same time, domestic traffic continued to grow rapidly, fueled mostly by increased service by Southwest Airlines. In order to meet Southwest's growing needs, the airport authority had committed to building new gates for Southwest's domestic operations (BWI Airport, 1998). After the loss of international traffic, there was a capacity-demand mismatch – too much

international capacity, not enough domestic capacity. The airport authority could have avoided such a costly mistake if it had designed the new pier to be multifunctional. Then, the gates and terminal space not being used as a result of the loss of U.S. Airways international traffic could have (at least temporarily) been used by the growing domestic traffic needs. The airport authority would have saved on all or part of the cost of building the new domestic gates, at the relatively small added expense of building a swing gate system. In short, the decision-makers gambled that the future growth in international traffic was a certainty, and are paying for it through costly underutilization and early expansion of domestic facilities.

Future operating procedures are as uncertain as the traffic mix. If airlines and partners find that swing aircraft designation between international and domestic would be beneficial at some point in the future, having swing gates would allow for this as well.

4.3 Valuation Methods

Unlike the previous examples of operational flexibility, in which benefits were calculated as the cost savings of improving current utilization and guarding against the cost of delay, it is not certain if strategic flexibility will be put into effect because the future demand mix is uncertain. The insurance value of strategic flexibility is a function of the chance that change will occur in the future, the cost implications of that change, and the degree to which these costs can be avoided through flexibility.

4.3.1 Real Options

Real options valuation is a method used to analyze investments under uncertainty. It is based on option pricing theory, used by financial analysts to value call and put options on

securities. An option provides a right, but not an obligation, to buy or sell a security at a predetermined price. The option is valuable because it is uncertain whether the price in the future will be higher or lower than the predetermined transaction price, offering the benefit of a potentially high upside gain while limiting the downside loss to the cost of acquiring the option. The value of the option is a function of the current price of the stock, the volatility of the price of the stock, the future price at which the option is exercised, the time until the option is exercised, the cost required to exercise the option, and the risk-free interest rate.

Real options are actual project investment decisions that can be modeled – and therefore valued – after options on financial securities. Several types of real options have been modeled, including time to investment, abandonment, temporary shutdown, growth, input flexibility, output flexibility, and expansion options.

In this case, the real option provided by multifunctional facilities is output flexibility. Different output (type of capacity) can be provided depending on the demand mix. The investment decision relates to the capacity allocation in airport passenger buildings and its cost implications. The challenge is to identify the relevant factors in the problem of passenger buildings which parallel those affecting the value of financial options. However, a real options valuation is unrealistic here for several reasons. There is not enough of the right kind of data to do an analysis with any expectation of accuracy. Additionally, there is too much slack in the system for dynamic switching to be valuable as demand fluctuates, as in the input flexibility case of the flexible fuel burner to price fluctuations described in Chapter 1.

4.3.2 Decision Analysis

In lieu of real options valuation, decision analysis is used to estimate the value of a real option. Decision analysis provides a structured way to make decisions under uncertainty, identifying optimal strategies for development. Decision trees organize the design decisions to be made, the range of possible scenarios which influence the cost-effectiveness of the decision, their probabilities, and the cost implications of each decision with respect to each scenario. These models allow designers to estimate the possible implications of each capacity allocation decision, providing a better understanding of the relationship between the decisions and their consequences. The optimal decision minimizes the total cost of the expected outcome, or alternatively, maximizes the potential revenue.

4.4 Design and Valuation Procedure

Decision analysis requires the identification of possible future scenarios, their likelihood, their cost implications, and the degree to which these costs can be avoided through flexible capacity allocation. Note that while the analysis is only done for the case of improving capacity utilization to avoid future construction, an identical analysis could be done with respect to the cost savings of swing aircraft designation, for example. Additionally, as described in the chapter introduction, the analysis is done within each “block” of capacity expansion. So, the planning horizon is defined in increments of total capacity instead of for a given year, as recommended by Bluestone (1979) and used by many airports for planning.

The driving force, then, is uncertainty in the mix of traffic, not the absolute levels. Focusing on the mix instead of the absolute levels is important, because the mix captures the difference in the relative growth rates with respect to the growth rate of total traffic. The

possible mix of traffic depends on the variability of the possible mix around any forecast, and the range of possible forecast scenarios. The methodology analyzes the drivers for the range of future scenarios – normal variability and major shifts – separately. The normal variability can be superimposed onto the possible future scenarios defined by major shifts. The optimal amount of swing capacity for each case is then summed to obtain the total flexibility recommended for future insurance. The value of swing capacity in providing insurance against the risks associated with future uncertainty depends on the possible range of the mix of future traffic.

4.4.1 Normal Variability

Figure 4.3 shows the general methodology for choosing the optimal provision of swing capacity to cover fluctuations in future traffic mix. Appendix III contains a detailed description of the methodology summarized below. Typically, future capacity is provided to meet a forecasted mix. However, volatility in the relative mix between users A and B implies that a probability distribution exists around the forecast mix within which the actual future mix will fall, shown conceptually in Figure 4.4. For any forecast mix, the first step consists of estimating the normal year-to-year fluctuations in the mix. It is reasonable to assume that regular annual variations associated with cycles in the economy will continue to exist in the future at least as much as it has in the past. Annual variability in the future is thus estimated from historic variability around a long-term trend. Calculate the mix of traffic, defined as $\frac{A}{A+B}$, for the past n years. Next, fit a linear trend to this data and compute the standard deviation, s , using each year's deviation from the trend.

$$s = \sqrt{\frac{\sum_{i=1}^n (\text{actual}_i - \text{trend}_i)^2}{n-1}} \quad (5)$$

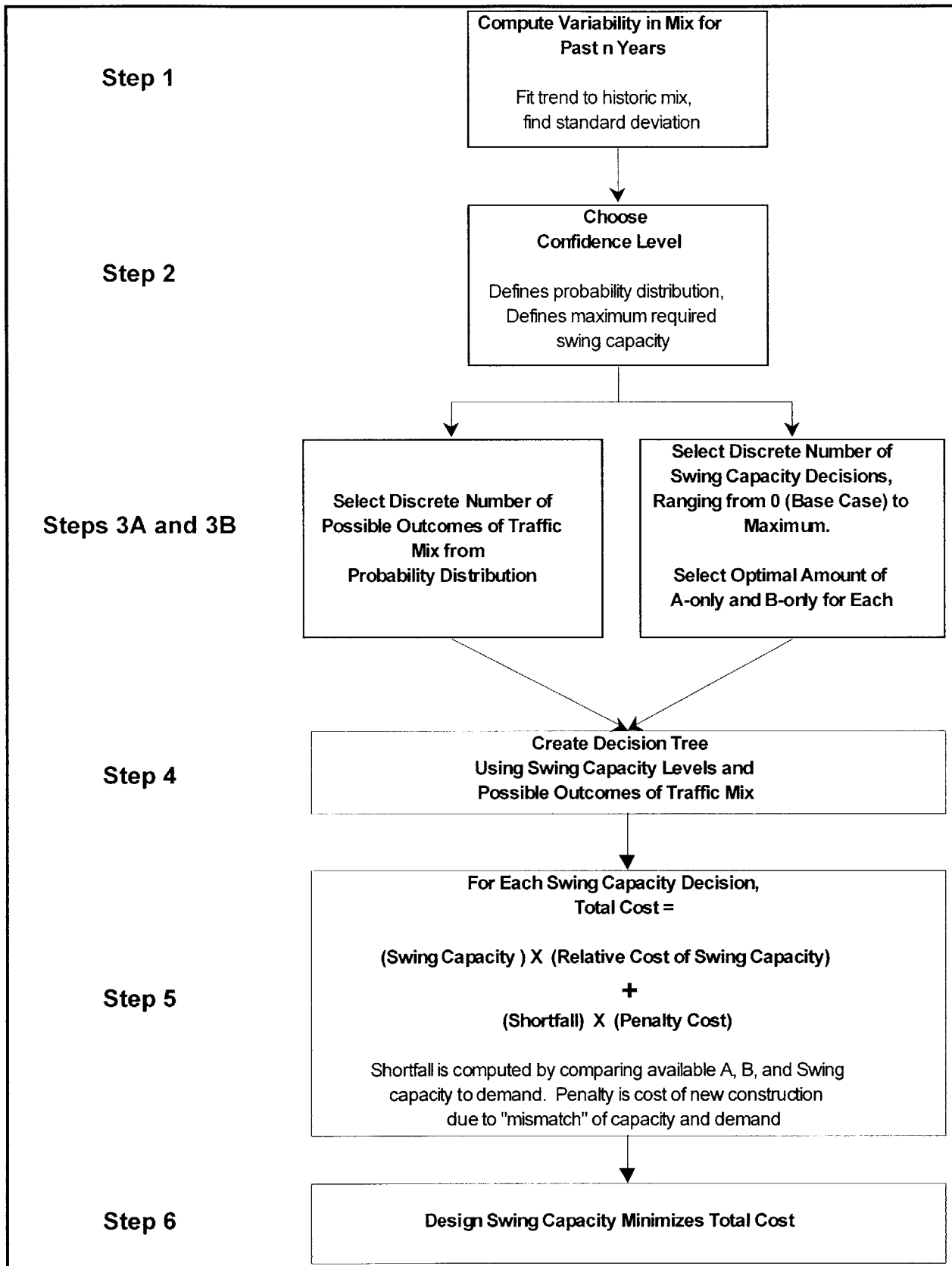


Figure 4.3. Methodology for Choosing Optimal Flexibility to Normal Variability

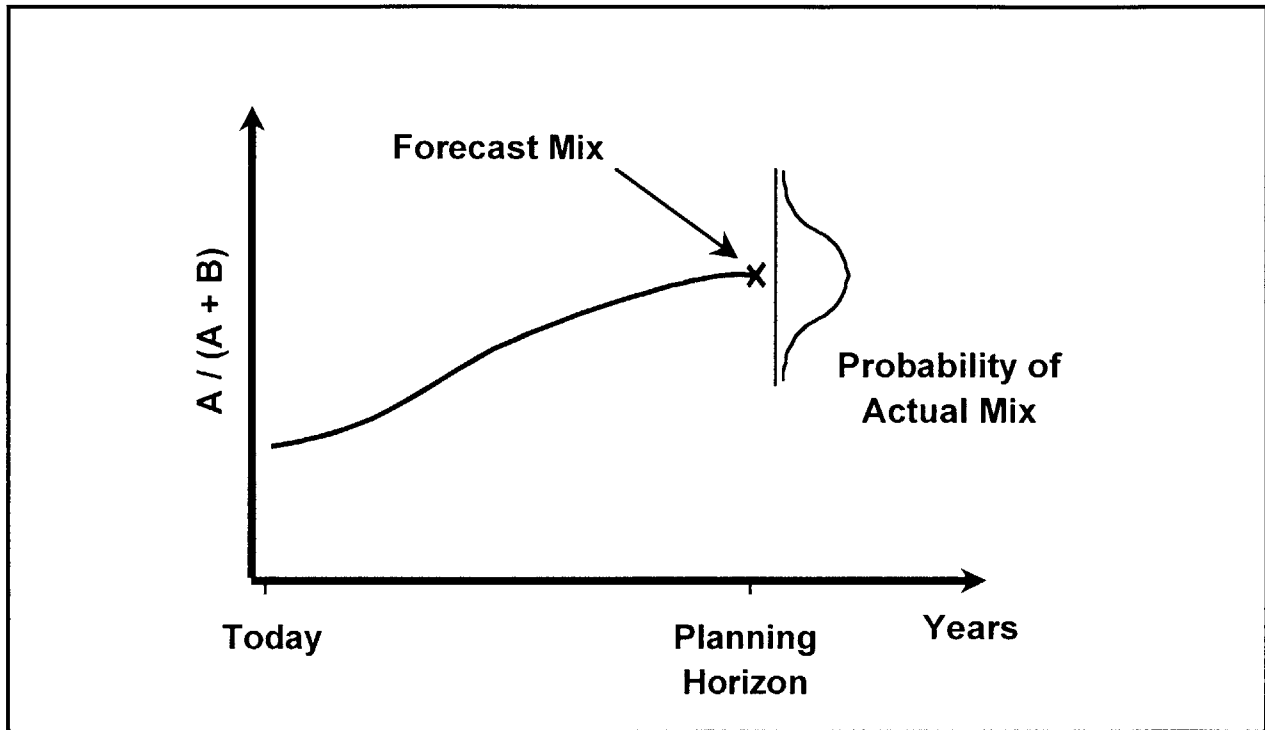


Figure 4.4. Annual Variability Creates Probability Distribution of Actual Around Forecast

The second step requires that the designer choose the level of confidence defining the range within which the actual mix will fall. This confidence interval essentially defines how much risk the airport is willing to take with respect to normal variability. A high confidence interval, say 99%, implies that there is a 99% chance that the actual mix will fall within the range around the forecast defined by the normal variability (lower risk). A low confidence interval, say 70%, implies that the airport is only worried about covering 70% of the possible range defined by the normal variability (higher risk). The standard deviation and confidence interval together define the range and probability of different future outcomes for the decision tree.

Step 3A defines the possible outcomes that will be included in the decision tree. To keep the decision tree manageable, the range is broken up into several possible outcomes of actual traffic mix at the planning horizon. The probability of each outcome is determined by computing

areas of the probability distribution around each point outcome. Appendix III shows this procedure.

Similarly, Step 3B defines several decisions on the amount of swing capacity. The base case scenario defines the minimum number of swing gates to consider – none. In the base case, all capacity will be either A-only or B-only, chosen according to the expected values of A and B defined by the forecast mix. The maximum amount of swing capacity to consider is the size of the range, defined by the standard deviation and the confidence interval – any more swing capacity would be too much flexibility for the level of uncertainty. To provide intermediate choices between the two extremes, the designer then divides this range into a discrete number of decisions to be analyzed in the decision tree. For each of these decisions on the number of swing gates there are several combinations of A-only and B-only capacity which are feasible. The decision tree allows for the optimal combination of A and B capacity for each decision on swing capacity, depending on the probabilities of the actual mix defined by the standard deviation and the confidence interval.

Step 4 consists of entering the design decisions on swing, A-only, and B-only capacity decisions, the possible outcomes of future traffic mix, and their probabilities into the decision tree. Treeplan, a decision analysis macro for use with Microsoft Excel, is used to implement the decision tree. The decision tree will be used to determine the initial decision on the amount of swing, A-only, and B-only capacity which leads to the minimum expected value of total costs.

Step 5 computes the expected value of total cost for each decision under each scenario of the future mix. Total cost is defined by the cost of swing capacity for any decision and a penalty applied for needed future construction if a shortfall exists, where the shortfall is function of the amount of swing capacity and the amount of A and B only capacity. Depending on how much

swing capacity is provided, deviations of the actual from the expected mix may be covered because the swing capacity can be reallocated to user A or B depending on the actual outcome. The cost of swing capacity is defined as a relative percentage of the cost of gate construction. This allows for calculation of percent savings without having actual unit construction cost estimates. Figure 4.5 shows an abridged version of the decision tree for an airport planning for 30 gates, with a forecasted mix of 77 %A, historic and thus future normal variability of 7 %A, and analyzed for a 95% confidence interval. The tree includes five swing gate decisions and five possible outcomes of the future mix.

Step 6 scans the decision tree for the decision which minimizes the expected value of total cost. The spreadsheet implementation of the model allows the designer to test different values of these assumptions on the recommended decision for swing capacity. The decision analysis is run for several combinations of standard deviation and relative cost of swing gates to create Figure 4.6. The values plotted in the figure represent the swing gate decision that leads to the minimum expected value of total costs for each combination of relative cost and standard deviation.

The results are intuitive. For a given standard deviation of the traffic mix, the optimal swing capacity decreases as its relative cost increases. For a given relative cost, the greater the standard deviation the more swing capacity required as a percentage of total capacity.

Beyond a relative cost of about 30 percent the additional cost of swing capacity begins to outweigh the benefits of avoiding future costs, and the recommended portion of swing capacity drops below 5%. For international/domestic swing gate, preliminary estimates indicate that the cost of the swing gate-sterile corridor system may represent only 5 to 10% of the cost of gate construction. Total sterile circulation at Miami/International is approximately 220,000 square

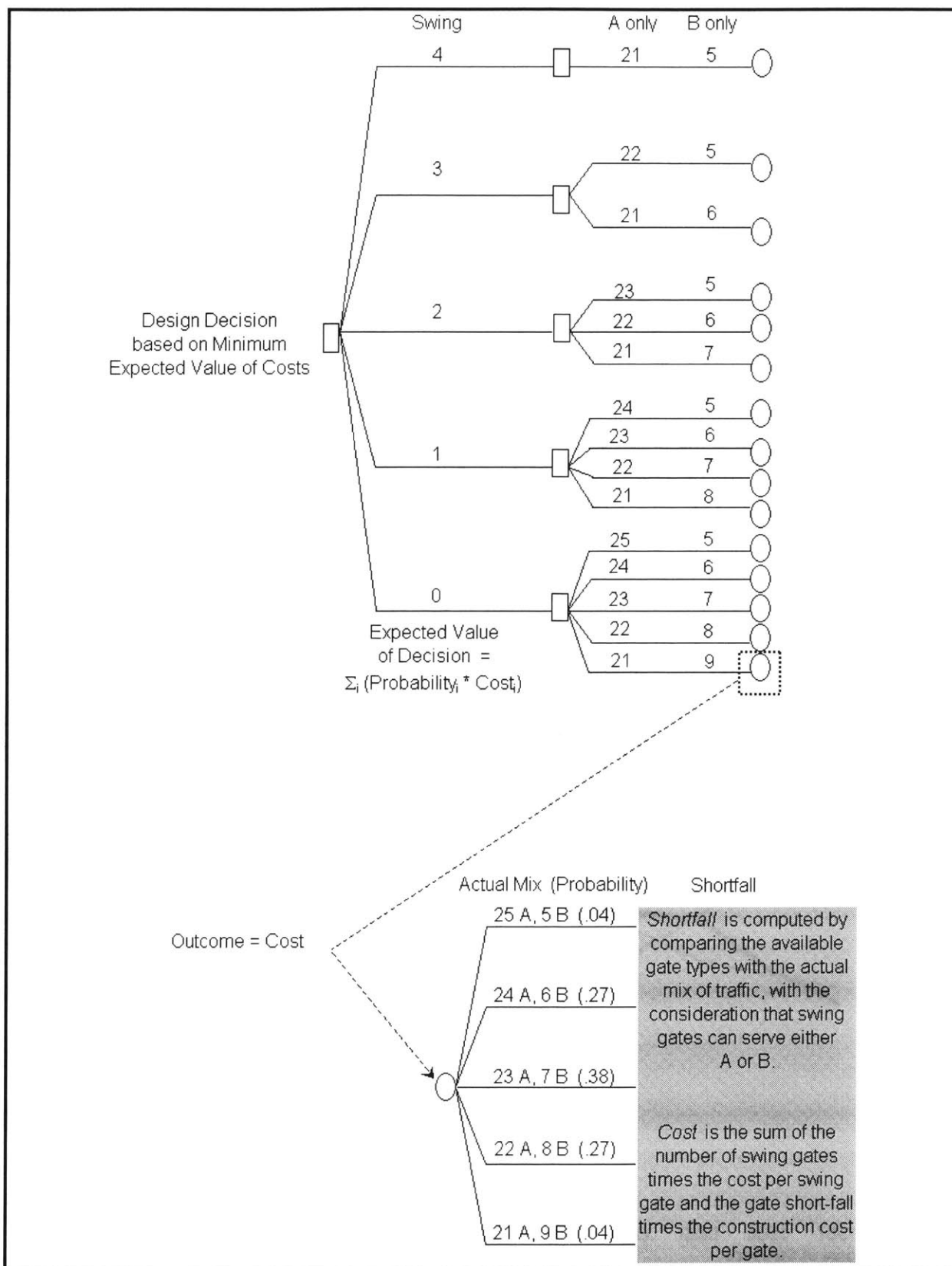


Figure 4.5. Decision Tree Example of Number of Swing Gates for Annual Variability, Total Gates = 30, Expected Mix = 77% A, Standard Deviation = 7% A, 95% Confidence

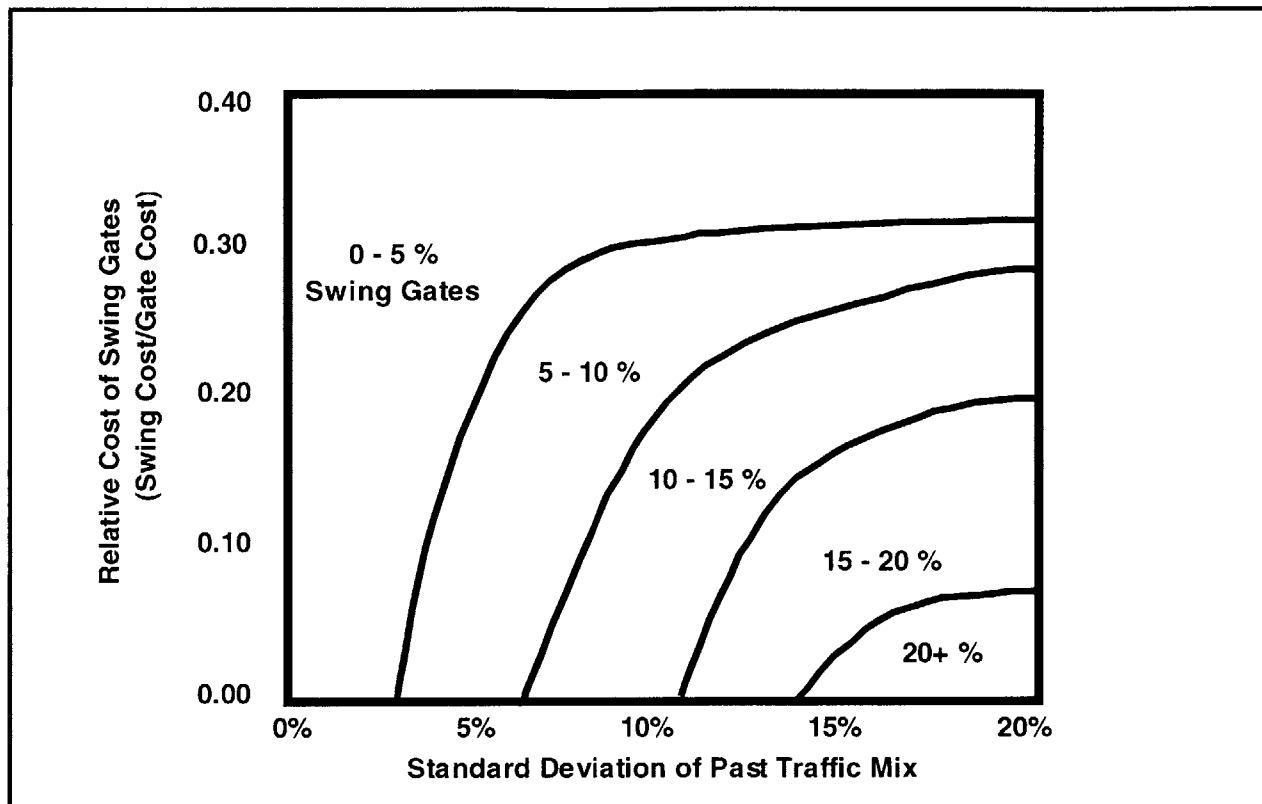


Figure 4.6. Optimal Swing Capacity as a Percentage of Total Gates – Normal Variability

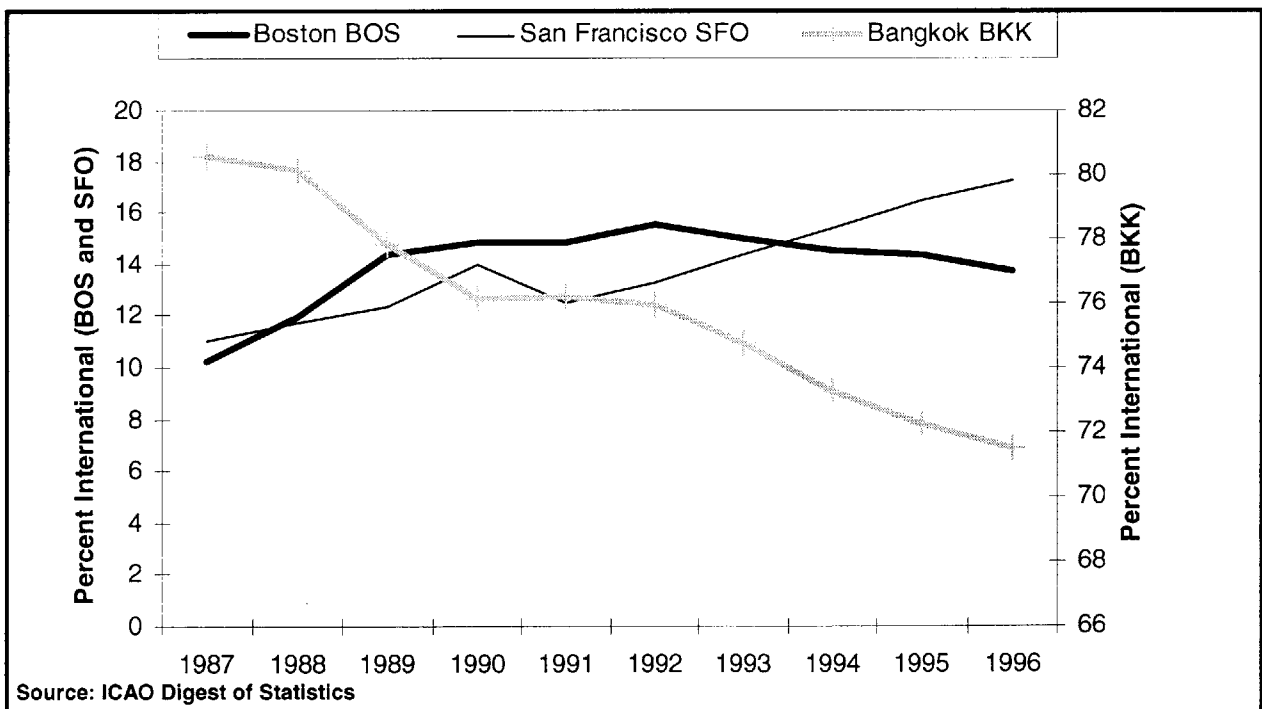


Figure 4.7. Historic Volatility at Boston, San Francisco, and Bangkok

feet (Landrum & Brown, 1994). At \$300 to \$500 per square foot, a reasonable estimate for the construction cost of passenger building space, the sterile circulation leading from the gates to the FIS costs approximately \$65 to \$110 million. Miami has approximately 60 swing gates, so the approximate cost per swing gate is about \$1 to \$1.8 million. Depending on what is included, gate construction may cost \$10 to \$25 million per gate. So, the relative cost of swing gates may range from about 5% to 20%.

Figure 4.6 plots the amount of swing capacity for standard deviations between 5 and 20%. For international/domestic multifunctionality, the standard deviation of the traffic mix might not get as high as 20%. Figure 4.7 displays the international mix at Boston/Logan, San Francisco/International, and Bangkok/International between 1987 and 1996. The standard deviation of international mix was only 1.4%, 0.6%, and 0.6%, respectively. The current forecast for Boston calls for 37.5 million annual passengers (MAP) in 2010. Based on past variability, Logan should have at least 1 swing gate to cost-effectively deal with variability in international / domestic mix. The current forecast for San Francisco anticipates 63 MAP by 2006. One or two swing gates would be sufficient to cover annual fluctuations in traffic mix there. The first phase of development at the Second Bangkok International Airport provides capacity for 30 MAP, also requiring one or two swing gates to cover normal annual variations.

In some sense, since the annual variation has been experienced in the past and will continue into the future, the recommended swing capacity for normal variability represents the minimum multifunctionality that should be provided as insurance against the risk of mis-design. The real question, however, is how confident are planners that the actual mix 10, 20, or 30 years from now will be exactly as forecasted? More multifunctionality is needed if the possibility of major shifts exists, which the volatile environment of deregulation makes increasingly likely.

4.4.2 Major Shift in Traffic Mix

The range of possible futures becomes much larger when one thinks about all of the possible events that could affect future traffic. For the case of international/domestic mix, several possible events could bring a major shift in the future: 1) Airport becomes international hub, 2) Airport remains at present mix, 3) Airport bypassed as hub, international traffic flies directly to destination. Scenarios 1 and 3 could lead to fundamental shifts in the traffic mix away from the current trend. Similar events could be defined for future aircraft mix or airline mix.

This analysis looks at the implications of the range of scenarios and their relative likelihoods on the cost savings provided by swing capacity. Figure 4.8 is a flowchart describing the procedure. Appendix IV describes the analysis summarized below in more detail.

The first step is to determine the future mix that could be expected from current trends. In Step 2, forecasters and planners estimate the magnitude and likelihood of possible shifts away from the prevailing trend according to different scenarios, as described above for shifts in the international/ domestic mix. The shift is defined as an absolute change in the percent traffic mix. For each scenario, the range in traffic mix is the difference between the expected mix and the major shift scenario. So, if the expected mix is 20% international, a 10% shift would represent a mix of 30% in the future.

This structure offers practical usefulness because it allows planners to compare the expected position with the possibility of a shift in the mix, either up or down. The model can sufficiently cover all scenarios as the size and probability of the shift vary. Unlike in the case of normal variability, past data cannot be used to estimate the probability of a given mix since the major shift is by definition a unique and unpredictable event. Step 3A requires that the planner

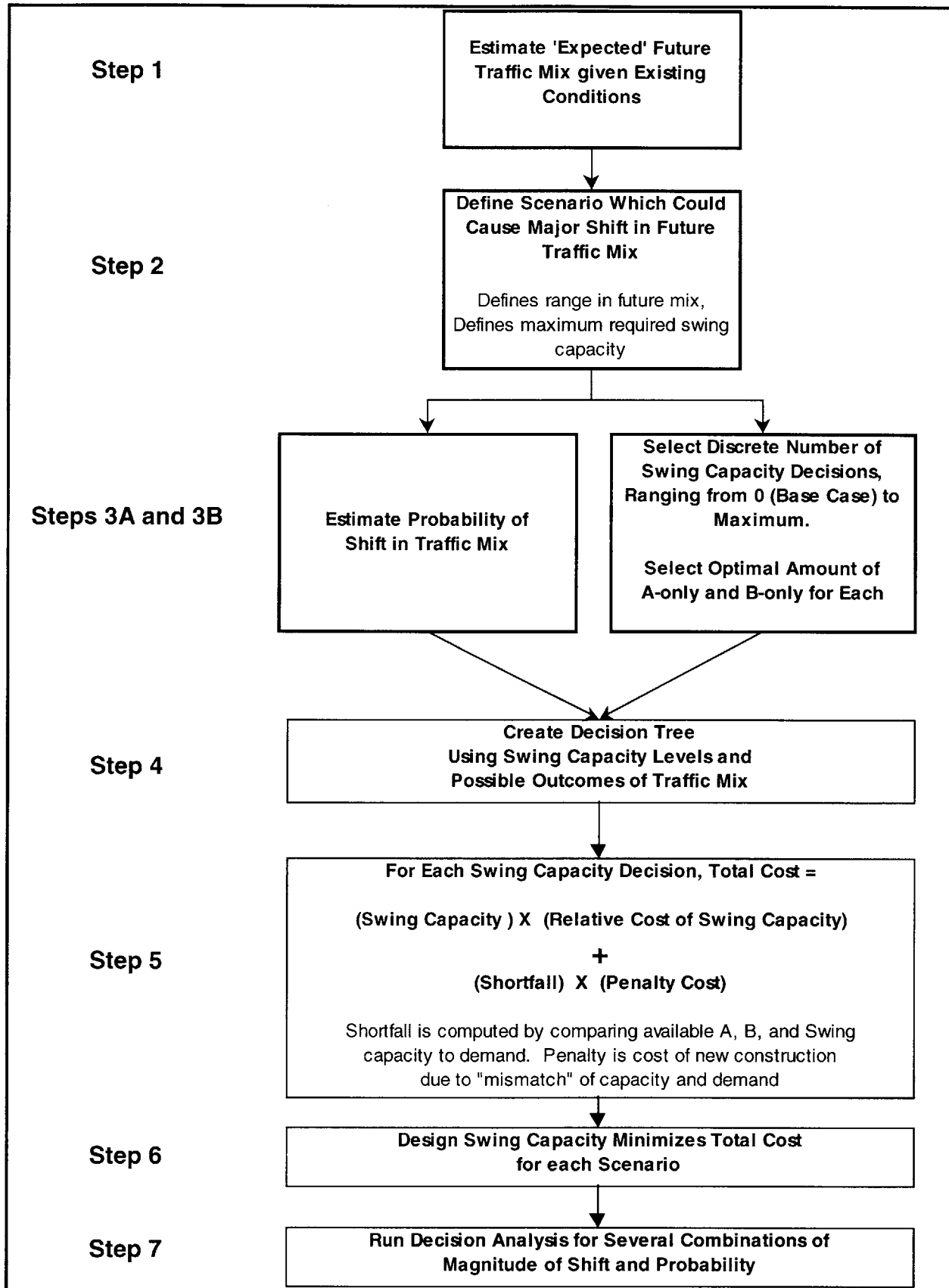


Figure 4.8. Methodology for Choosing Optimal Flexibility to Major Shift

speculate on the probability of the change. The decision tree is used to explore sensitivity of the optimal provision of swing capacity to this probability.

Again, Step 3B defines several decisions on the amount of swing capacity. The base case scenario defines the minimum number of swing gates to consider – none. In the base case, all capacity will be either A-only or B-only, chosen according to the expected values of A and B, defined by the forecast mix. The maximum amount of swing capacity to consider is the size of the range, defined by the standard deviation and the confidence interval – any more swing capacity would be too much flexibility for the level of uncertainty. To provide intermediate choices between the two extremes, the designer then divides this range into a discrete number of decisions to be analyzed in the decision tree. For each of these decisions on the number of swing gates there are several combinations of A-only and B-only capacity which are feasible. The cost-minimizing combination of A-only and B-only gates accompanies each decision on the number of swing gates.

Step 4 sets up a decision tree for the swing capacity decisions and the cost implications of the shift in mix and its probability. Figure 4.9 shows an abridged version of a decision tree considering four swing gate decisions, where R is the product of the range on the future mix times the total number of gates. As before, Step 5 computes the expected value of total cost for each decision under each scenario of the future mix, defined by the cost of swing capacity for any decision and a penalty applied for needed future construction if a shortfall exists. The shortfall is a function of the amount of swing capacity and the amount of A and B only capacity. Depending on how much swing capacity is provided, deviations of the actual from the expected mix may be covered because the swing capacity can be reallocated to user A or B depending on the actual outcome. The cost of swing capacity is defined as a relative percentage of the unit

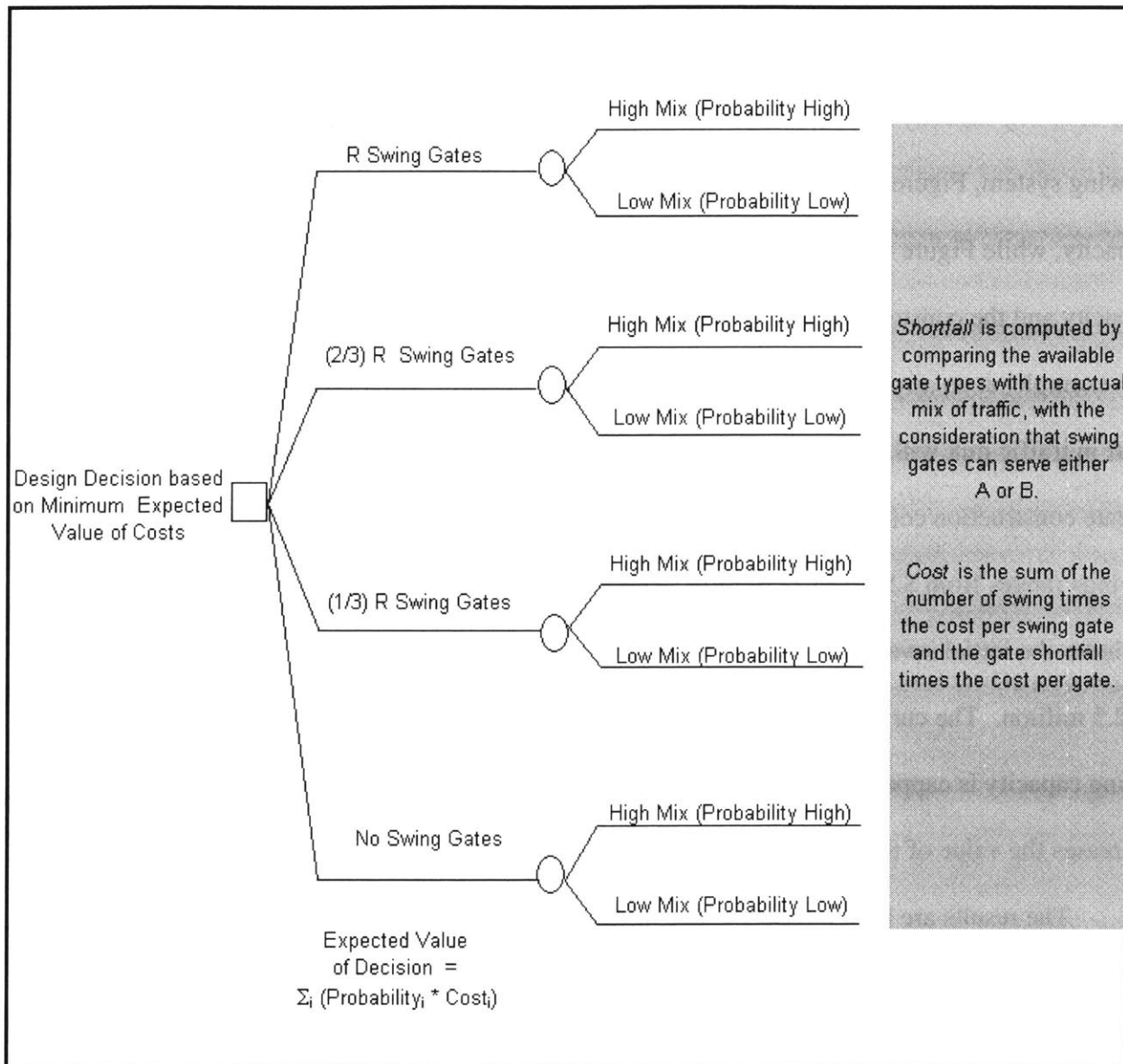


Figure 4.9. Decision Tree for Major Shift in Traffic Mix

cost of capacity construction. Step 6 scans the tree for the decision which minimizes the expected value of total cost. In step 7, the designer tests the different values of the shift and its probability on the recommended decision for swing capacity.

The decision analysis is run for several combinations of standard deviation and relative cost of swing capacity to create Figures 4.10 and 4.11. For different values of the relative cost of a swing system, Figure 4.10 shows the optimal multifunctionality as a percentage of total capacity, while Figure 4.11 shows the expected value of cost savings normalized by the total capacity and the construction cost per unit of capacity for the optimal decisions in Figure 4.10. For example, at an airport with 50 gates, with a relative cost of 5%, a 30% probability of a 20% shift in traffic mix will lead to total savings about 2.5 to 5 times the construction cost of a gate. If gate construction costs from \$10 to \$25 million depending on what is included in the cost, the savings ranges from \$25 to \$125 million. This seems worthwhile, considering that this savings includes the initial investment in 20% swing capacity (10 gates), which itself only cost \$5 to \$12.5 million. The curves in Figure 4-9 differ from those in Figure 4-8 because the maximum swing capacity is capped at the size of the range, but as the probability of the shift scenario increases the value of the cost savings continues to increase.

The results are both intuitive and powerful. The wider the range, the higher the likelihood of the shift scenario, and the cheaper the cost of the swing gate system, the more value can be gained from having swing gates. By construction, the maximum amount of swing capacity is the size of the range itself. This is similar to the result shown in Figure 2.25. In Chapter 2, the benefits of multifunctionality are certain – space and cost reductions come

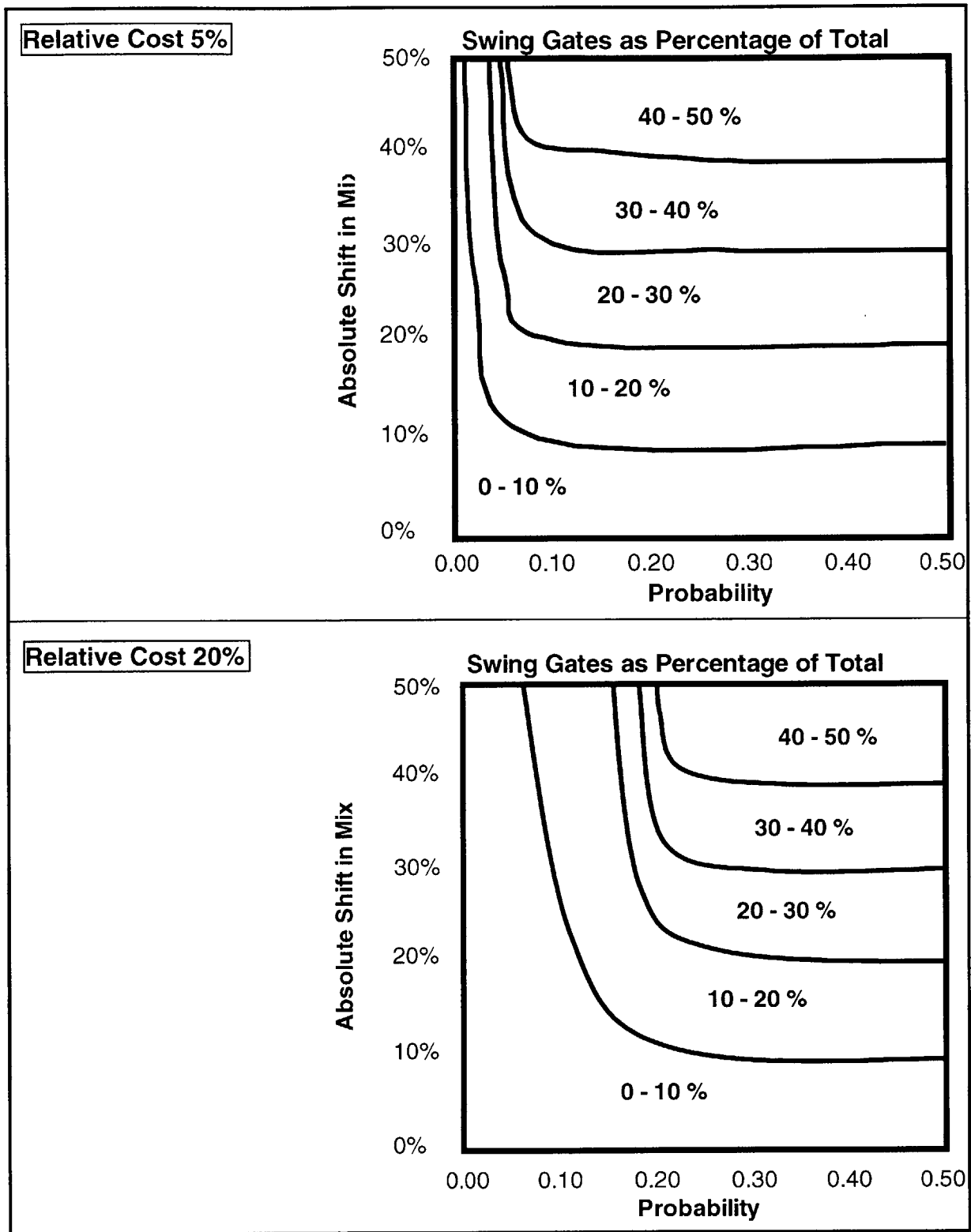


Figure 4.10. Number of Swing Gates as Percentage of Total Gates

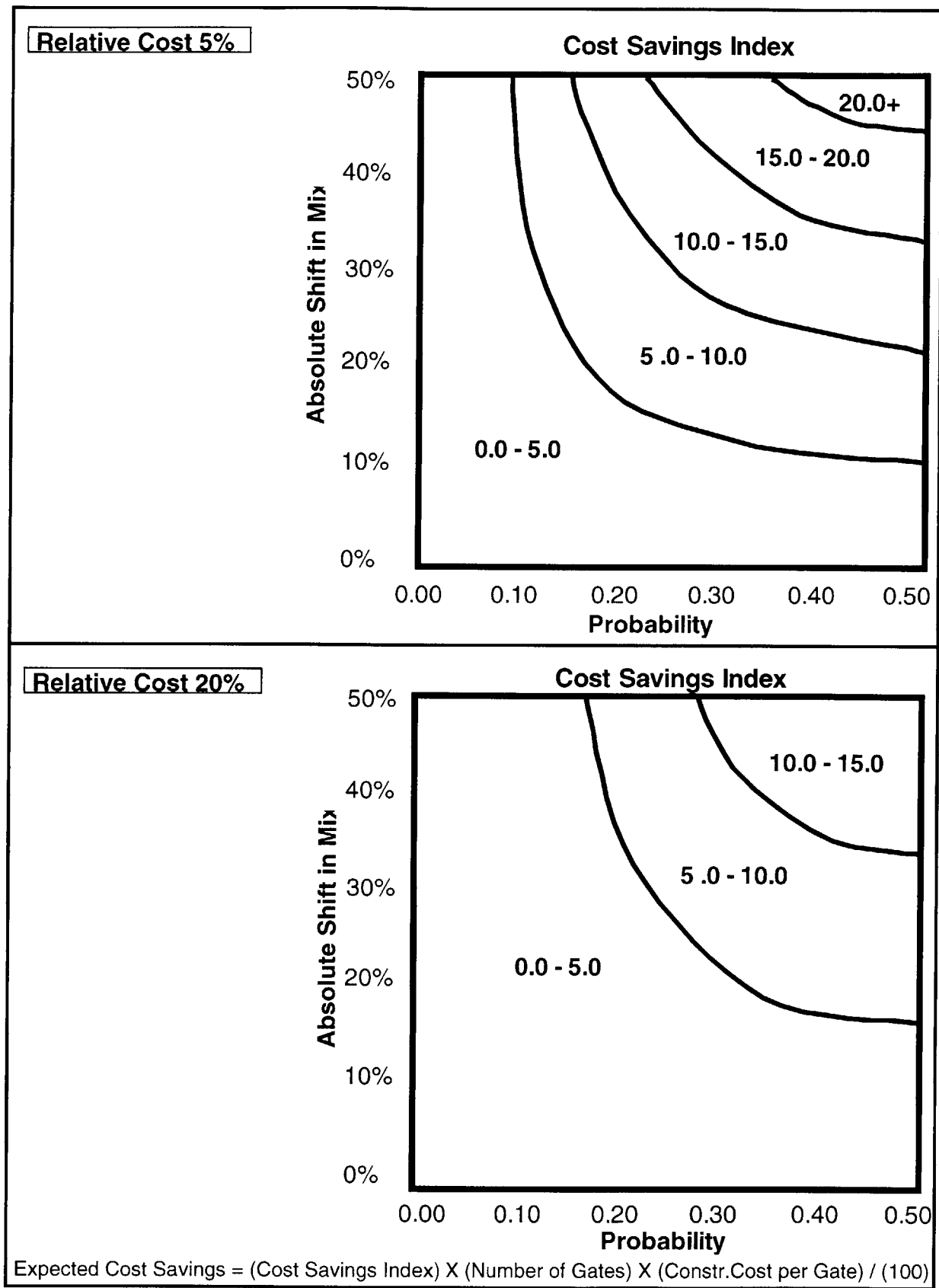


Figure 4.11. Expected Value of Cost Savings Normalized by Construction Cost per Gate

immediately. The difference here is that since the benefits – avoiding the penalty of redevelopment costs – are not certain. The minimum-cost number of swing gates may be less than that defined by the range because the expected value of total costs for each decision is a probability weighted average based on the size of the shift, its cost implications, and its likelihood.

For scenarios of traffic mix shifts that are not very likely, the number of swing gates is highly sensitive to their probability, especially when the relative cost is high. In these situations, the optimal amount of swing capacity can be estimated from the graphs in Figure 4-10. However, if the scenario is less than trivial, the insurance provided by the ability to reallocate capacity outweighs its cost, even for as the relative cost of swing capacity increases to 20% of the penalty cost. For reasonably likely scenarios, the optimal swing capacity is equal to the range of possible futures and is independent of its cost.

The second international airport for Bangkok, Thailand serves as an example for analysis of a major shift in traffic mix. Planners envisioned a range of possible international and domestic traffic levels at the 30 and 60 MAP development stages. The range was based on the possibility of two scenarios: the airport remains near its current mix or it becomes an international hub and the mix increases substantially. At 30 MAP, planners estimated that international traffic could range between 21 and 25 MAP (70 to 84% international), with the corresponding domestic traffic between 5 and 9 MAP (16 to 30% domestic). At 60 MAP, planners estimated international traffic could range between 45 and 51 MAP (75 to 85% international), with domestic traffic correspondingly between 9 and 15 MAP (15 to 25% domestic). These represent ranges of 14% and 10% on the international mix at 30 and 60 MAP, respectively. Assuming there is at least a 20% chance the hubbing scenario will develop and the

relative cost of international / domestic swing gates is between 5 and 20 percent of the construction cost of a gate, Bangkok should include about 10 to 20% swing gates to most cost-effectively cover the possible range. Assuming each gate serves approximately 0.5 MAP, this translates to 6 to 12 swing gates for the 30 MAP stage and 12 to 24 swing gates for the 60 MAP stage.

4.4.3 Recommended Insurance for Future Uncertainty

Sections 4.4.1 and 4.4.2 separately provide methodologies for determining the optimal swing capacity as insurance against the uncertainty in future traffic mix caused by normal fluctuations in annual levels and the possibility of major changes. These two forces should be considered together, as both probably exist at every airport.

Normal variability in traffic mix will undoubtedly exist at an airport in the future, at least as much as it has in the past. This defines the minimum number of swing gates to provide, allowing for reallocation annually as the mix fluctuates.

Major shifts define the impacts of possible events that could lead to a fundamental, long term change in the traffic mix. The optimal percentage of swing gates from section 4.4.2 defines the most cost-effective provision of multifunctionality to cover the range of possible outcomes from major shifts away from the expected mix.

As normal variability will exist regardless of the actual mix that develops – expected or shifted – the recommended provision of swing capacity as insurance for future uncertainty is the sum of that defined by the major shift and half of that defined by the normal variability. At either the high or low outcome, since the normal variability is assumed to be symmetric only half of the distribution could add or subtract from the high or low scenarios, respectively, to increase

the potential range on the mix. These arguments lead to the following recommendation for the provision of swing capacity as future insurance:

$$\text{Minimum Swing Capacity}_{\text{future}} = (\text{Optimal Swing Capacity for Normal Variability})$$

$$\text{Maximum Swing Capacity}_{\text{future}} = (\text{Optimal Swing Capacity for Major Change}) + (\text{Optimal Swing Capacity for Normal Variability}) / 2$$

Swing capacity can be provided according to which factors are important at an individual airport. If an airport's traffic mix fluctuates wildly from year to year, perhaps the swing capacity for normal variability overshadows that required for possible shifts. Alternatively, if potential shifts in traffic are looming or expected, the number of swing gates to cover this may dominate that required by small annual fluctuations.

The number of swing gates recommended to cover the range of future scenarios here does not include the number needed for present overlap of peaks and coverage of delays, as calculated in Chapters 3 and 4. The next chapter contains recommendations for implementing multifunctional facilities and reconciling the difference in recommended number of swing gates from current versus future considerations.

Chapter 5. Implementation and Recommendations

Flexibility is an important element in the design of airport passenger buildings because of the unique characteristics of the demand and users they serve. Designing flexibility into these facilities should be seen not merely as a desirable attribute, but instead as a way to proactively manage the total cost of the facility throughout its lifetime. This thesis identifies the benefits that can be achieved by its application in the right physical forms and quantities, allowing managers to mitigate the characteristics of demand that drive up facility's total cost per unit of capacity provided.

Variability and uncertainty in traffic and operations over time make separate facilities costly because they cannot serve different users or easily adapt to future needs. Multifunctional facilities provide operational and strategic flexibility in their allocation and use. This allows for reduction in total capacity requirements and provides insurance against the the risk of capacity-demand mismatch in the future. The value of this additional flexibility is precisely the cost and risk savings it provides. Depending on the degree of peaking and uncertainty, partial multifunctionality results in the best tradeoff between its benefits and additional costs.

The previous chapters have presented the motivation and methodology for providing multifunctional capacity. Figure 5.1 summarizes the forces driving down cost-effectiveness in the present and future, the multifunctional solutions that counteract these effects, and the valuation of benefits in each case. This chapter discusses combining these into a single approach, explores the interaction between multifunctionality and the other forms of flexibility, recommends how multifunctional facilities can be implemented, and provides suggestions for further research.

Driver	Issue	Typical Solutions	Value Comes From ...
Peaking	<u>Separate Facilities</u> : Results in Underutilization	Shared Use	Higher Utilization = Saved Space = Saved Cost
	Sequencing of Aircraft for International / Domestic Flows	Swing Facilities allows for Changeable Aircraft Designation	Fewer Wasted Resources and Increased Aircraft Availability
Uncertainty	Short Run: Variations from Schedule (e.g. Delays)	Sharing Spare Capacity to Cover Delays	Reducing Cost of Spare Capacity
	Long Run: Uncertainty in Future Operations and Growth	Adaptability: Multiple Possible Future Uses	Avoiding Future Construction

Figure 5.1. Summary of Benefits of Multifunctional Facilities

5.1 All-Inclusive Approach

The benefits of flexibility come both immediately, in terms of improved operations and utilization, and in the future through adaptability to unknown demand. Different traffic and schedule characteristics drive the value, and thus the provision, of flexibly-designed space and facilities. In reality, all of these forces are likely to be present in different degrees. The various methods for determining how much multifunctionality to provide need to be considered together.

5.1.1 Reconciling the Various Demands for Multifunctionality

The main distinguishing factor in the provision of multifunctional facilities is the time frame of analysis – improving efficiency of current operations or providing insurance against future uncertainty. Each time frame necessitates that a certain portion of total capacity is

multifunctional. For current operations, the recommended multifunctionality is the sum of that needed for peaking and that needed to share spare capacity. The recommended amount of multifunctional capacity for the future is somewhere between covering normal variability and covering major shifts, as section 4.4.3 describes.

Choosing between present and future needs, however, is less straightforward. How should the planner choose between current and future needs? Should the current and future needs be summed, or is there some overlap? Multifunctionality provided for the future re-allocation offers current efficiencies in addition to its insurance benefits. Likewise, multifunctionality provided for current operations also provides some insurance for the future. There is no way to determine a one-size-fits-all answer here. Instead, the decision is left up to the judgment of the planners. The separate analyses can, however, be combined to provide a range on the amount of multifunctionality to include. At the least, multifunctionality should be provided for the minimum of current and future needs. Providing this minimum amount guarantees that the airport will at least be in a better position than with no multifunctionality at all. The maximum multifunctionality to consider providing is the sum of current and future needs – any more would be too much flexibility for the amount of peaking and uncertainty present. Planners would then choose from within this range the amount of multifunctionality to provide given the situation at the individual airport, as Figure 5.2 diagrams. If the facilities are expandable, more multifunctional capacity can be added later if needed.

5.1.2 The Implications of Providing Both Multifunctionality and Expandability

To provide capacity cost-effectively over time, flexible planning must be accompanied by flexible design. Section 1.4 defines the different forms of flexibility in the provision and

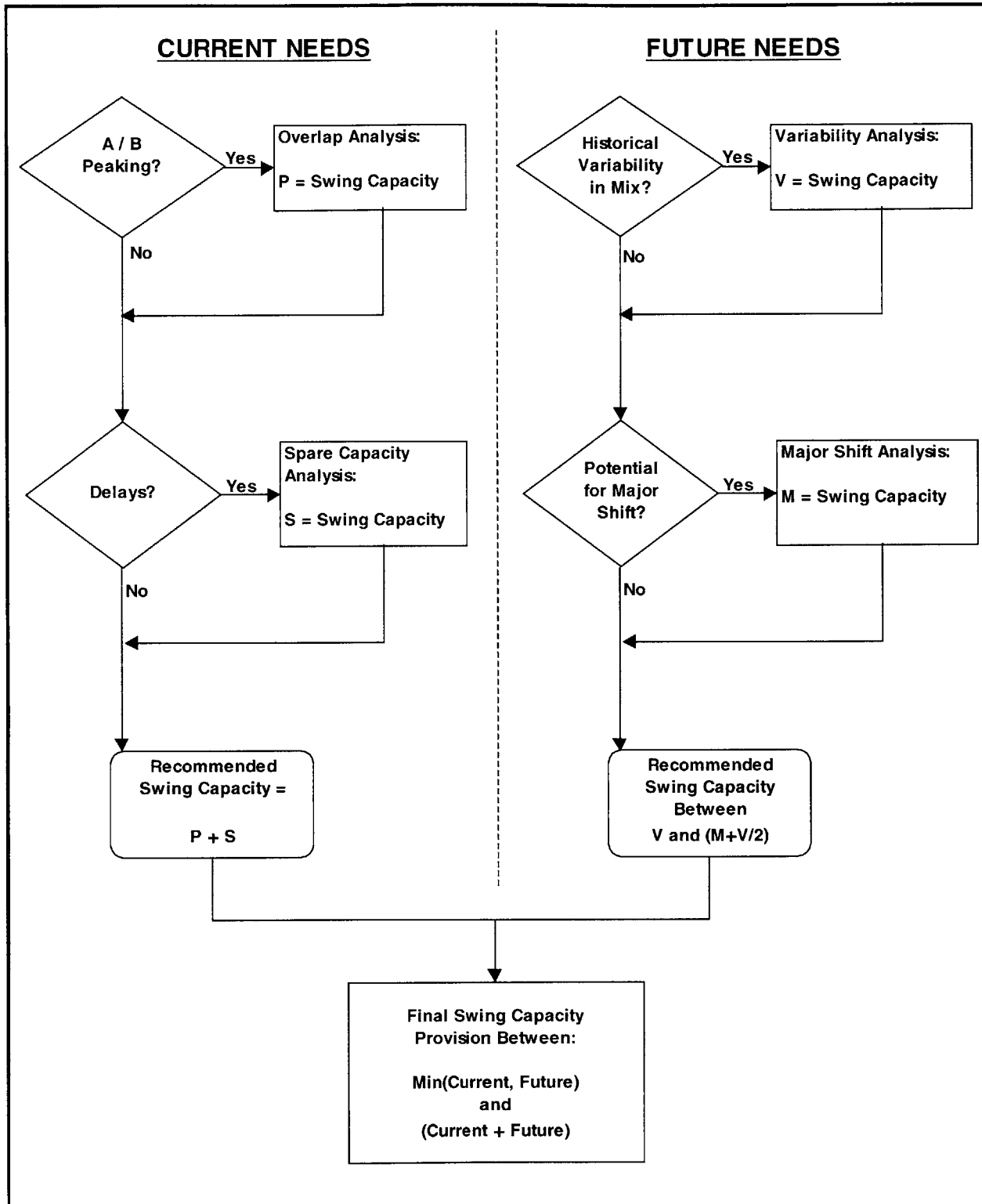


Figure 5.2. Determining Swing Capacity for Current and Future Needs

allocation of airport passenger building capacity. If, as recommended, both multifunctionality and expandability are to be provided, extra consideration must be given to their interaction.

The benefit of multifunctional capacity in the short term is that it allows for sharing of space and facilities. This results in higher utilization over the day, reducing the total capacity that needs to be provided, which Figure 5.3 shows. This increases the need to be able to expand quickly because there is less slack in the system to cover unexpectedly high growth. Rapid expandability is thus of paramount importance when facilities are shared and utilization is high. Non-fixed capacity, such as remote bus gates and transporters, provide temporary short term expandability to cover surges in demand while new fixed capacity is being built.

Over the long term, multifunctionality pushes back the time to expansion because capacity can be reallocated to meet the actual traffic mix. Reallocability prevents the chance of a capacity-demand mismatch, which happened at Washington/Baltimore. Chapter 4 describes how international traffic, which had been growing rapidly, suddenly dropped around the same time new international gates were being built. The international pier was not designed with swing gates, and so growth in domestic traffic required new domestic gates to be built while the international pier was left underutilized. In short, total capacity had to be expanded prematurely because there was no flexibility to match the existing capacity with the actual demand. Figure 5.4 illustrates this phenomenon.

Conversely, expandable capacity provided in very small increments, say one gate at a time, would make capacity reallocation in the future less important because the right type of capacity could be provided as it is needed. In general, however, it is not cost-effective or realistic to expand in such small increments.

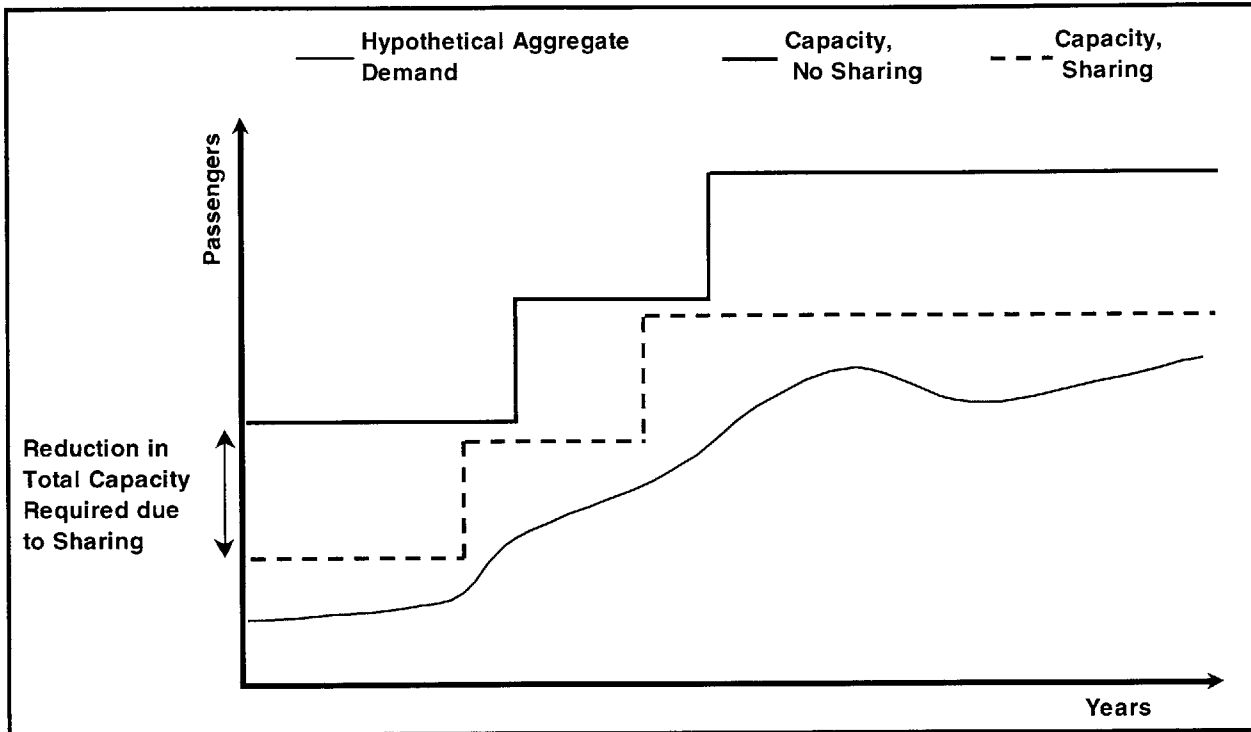


Figure 5.3. Sharing Leaves Less Slack, Increasing the Need for Rapid Expandability

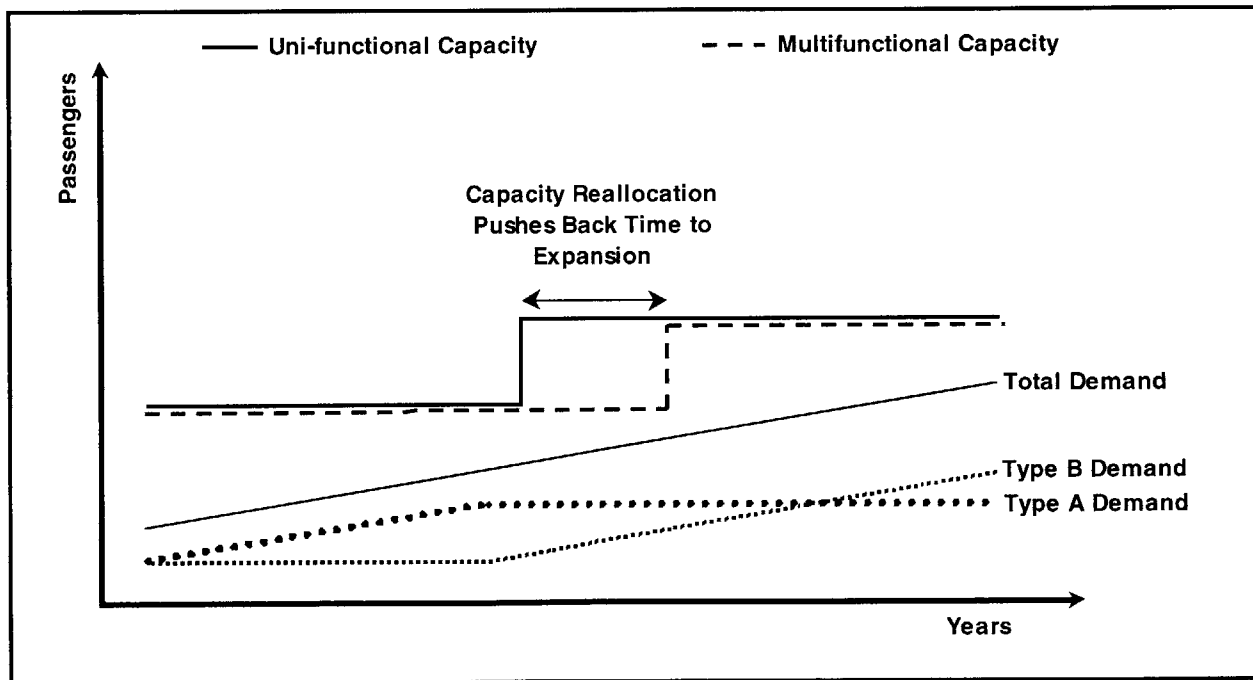


Figure 5.4. Multifunctional Facilities can be Reallocated in the Future, Preventing the Need for Premature Expansion (Assumes no Daily Overlap of Peaks)

5.2 Recommendations for Planning, Design, and Management of Flexible Capacity

The previous chapters argue that peaking and uncertainty make separate facilities uneconomical because they offer less flexibility in capacity allocation. While the analysis has offered an approach to providing the optimal amount of multifunctionality, the discussion has only touched the surface on some of the practical issues on implementing sharing. This section discusses some of the practical management issues related to planning, designing, and managing flexible capacity.

The costs of flexibility are tangible. Any contractor can offer a cost estimate for building in flexibility in a particular form – flexible loading bridges, swing gates, etc. This thesis thus focuses more on quantifying the benefits of flexibility than dealing with its costs and negative impacts. The fundamental premise of the recommendation to provide some shared multifunctional facilities is that wholesale separation of different users – defined as airlines, aircraft types, international and domestic flight sectors, etc. – is cost-ineffective in both the present and the future.

There are several reasons why separate facilities are often provided. For one, they are less complicated than multifunctional ones, and people in general prefer to focus their analyses to as detailed and specific a level as possible. Secondly, airlines want their own facilities, separated physically from their competitors. For example, airlines typically oppose using CUTE, claiming it increases their costs because they have to make their internal systems compatible with the CUTE system. The real reason may simply be that they are not on good relations with their competitors and do not want to sacrifice market share or perceived dominance in a market by having to share facilities.

Leaders in local, state, and federal governments may rightly see investment in a sparkling new international passenger building as being an important driver for regional economic development and a signal to the industry that they are serious about attracting international traffic. However, a large investment may prove to be unwise and irresponsible if international traffic growth is volatile and uncertain. Designing the new building to be multifunctional (i.e., it also serves domestic traffic) is a more conservative way to expand, because if international traffic does not expand at least the space can be filled with domestic flights. The combined facility is also more attractive in terms of transfers between international and domestic and in improved airline operations, as Chapter 2 describes.

Existing facilities which are decentralized in nature may not lend themselves to multifunctionality and sharing. The unit terminal concept is prevalent at many airports, making sharing less achievable there. This is not a condemnation of shared facilities, but instead a motivation for not using unit terminals. Unit terminals may offer expansion flexibility because there is space between buildings, but offer little flexibility in reallocating capacity to users whose peaks do not coincide in the present or the future. Airports with unit terminals may not have been carefully planned as an entire system, as each terminal requires its own landside access system and an expensive system of buses or trains for passengers making connections between terminals. This may be one of the drivers for the most common design in more recent passenger building development – the common landside building connected to several airside concourses. The layout may be provided as a series of piers emanating out, as planned at Toronto/Pearson, or as satellites: “in parallel,” as at Tampa/International and Orlando/International, or “in series,” as the midfield concourses at Atlanta/Hartsfield and Denver/International. In all cases, the larger scale of the concourses offer both the airport and the airlines more flexibility in allocating and

using capacity. Expansion is easily attainable as piers and concourses can simply be added to the existing system. Appropriate over-design has been included where there would otherwise be bottlenecks when individual parts of the system are expanded. For example, the landside terminal may be slightly overbuilt so that if a new concourse is added on the system will still be in balance. Or even better, the landside terminal itself may have the capability to be expanded in line with expansions of the concourse capacity.

The reality is that as capacity becomes more constrained, federal subsidy decreases, and costs become more important, sharing at all levels will become necessary. Privately-developed and operated terminals – in which costs are of first importance – should and do focus on shared facilities. The arguments for separation hold less water when high costs and constraints to growth are both pervasive and less acceptable.

One solution may be the provision of some “hyper-flexible” facilities when capacity is at a premium. Take the example of gate positions. Hyper-flexible gates anchored to shared departure lounges with reconfigurable interior walls could be used by any airline, any aircraft size, whether the flight is international or domestic. These gates could cover non-coinciding peaks of different users, could serve as spare capacity in case of delays experienced by any user, and could easily be allocated in the future as users’ demands change. These gates would allow for improved facility utilization and improved resource utilization through swing aircraft designation. Hyper-flexible shared gates would not be under exclusive use leases – they would be run by the airport – to the benefit of both the airport and the airlines, who would have their own exclusive facilities elsewhere to cover their base needs. It would be a shame if these hyper-flexible gates go unused by airlines fighting over territory and unwilling to share. They should

instead be the most highly utilized and most valuable gates at the airport, precisely because of the flexibility they offer at so many different levels.

Shortening the length of airline leases at some gates improves the airport's ability to reallocate space and facilities. Some airports, including Miami/International, use 30-day leases for some of their gates. This is less valuable to the airlines, so the leasing rates will be lower than long-term lease rates. However, it provides the airport with more flexibility in capacity allocation, which might be worth taking in slightly lower rents.

Multifunctional, shared facilities inevitably increase the complexity of operations. Decisions must be made in real-time, allocating facilities to users in an environment characterized by dynamic, peaking, and uncertain demand in which delays and mistakes in judgment are extremely costly. Cost-effective design through sharing provides less margin for error. Several software firms offer "expert system" decision-support software exactly to deal with this problem, effectively increasing capacity through better management and allocation of personnel and facilities (Gosling, 1990). At least a dozen firms market proprietary software internationally, including Ascent Technology (U.S.); Sabre (U.S.); ARINC (U.S.); Honeywell (U.S.), Intersystems (U.S.); NAPA (Canada); The Preston Group, a subsidiary of Boeing (Australia); Aries (Spain); and SPEA (Italy).

These and other issues require further investigation.

5.3 Suggestions for Further Research

This thesis offers a comprehensive analysis of how to design and value flexibility in airport passenger buildings. As other research has focused on expandability and spare capacity,

the focus here is on multifunctionality. There are several issues that would further develop this research and lead to interesting results.

The analysis has been simplified because, aside from the case of shared departure lounge, it only considers overlap between two users, “A” and “B”. For international/domestic sharing this is acceptable, but when there are more than two airlines in consideration for shared facilities the analysis would become more complex.

Additionally, the analysis does not consider the different levels of defining who and what is sharing – i.e., the possible users sharing facilities include airlines, aircraft mix, and international and domestic traffic sectors. A more detailed analysis could explore the effects of sharing between and within these different levels for multiple users.

The analysis could also be improved by including the effects of economies of scale in the costs of building swing gates, and the effects of discount rate and inflation on the value of avoiding future costs. This analysis avoids these factors because the date of the planning horizon is not defined, only its total capacity level.

A more detailed study could improve the procedure for choosing the amount of multifunctionality to provide when there are conflicting current and future demands for its provision. Additionally, the provision and allocation of capacity when expandability, multifunctionality, and spare capacity are all used deserves further examination. An eventual goal could be a general cost-benefit model for flexible planning of capacity expansion, multifunctionality, and spare capacity all in one, considering their interactions and tradeoffs.

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Appendix I: Examples of Shared Departure Lounges

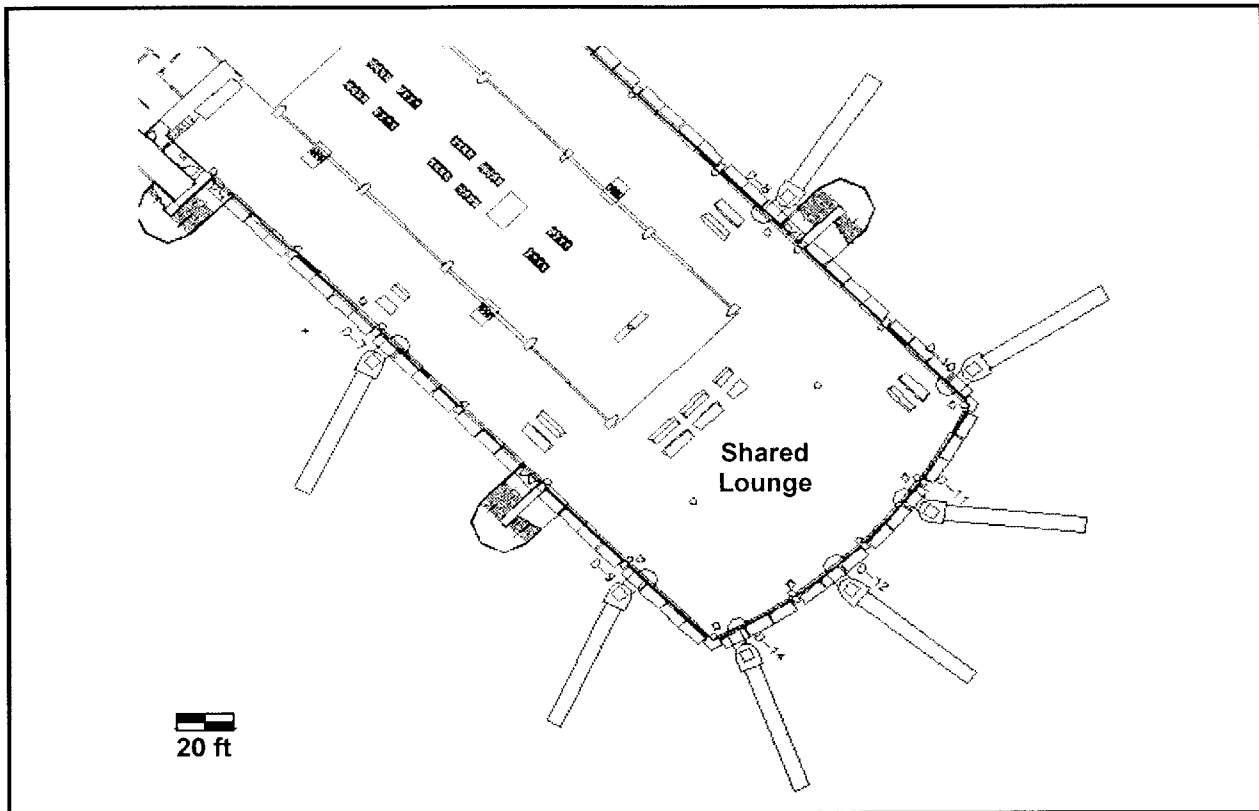


Figure A1.1. Shared Departure Lounge at Las Vegas/McCarran D Gates

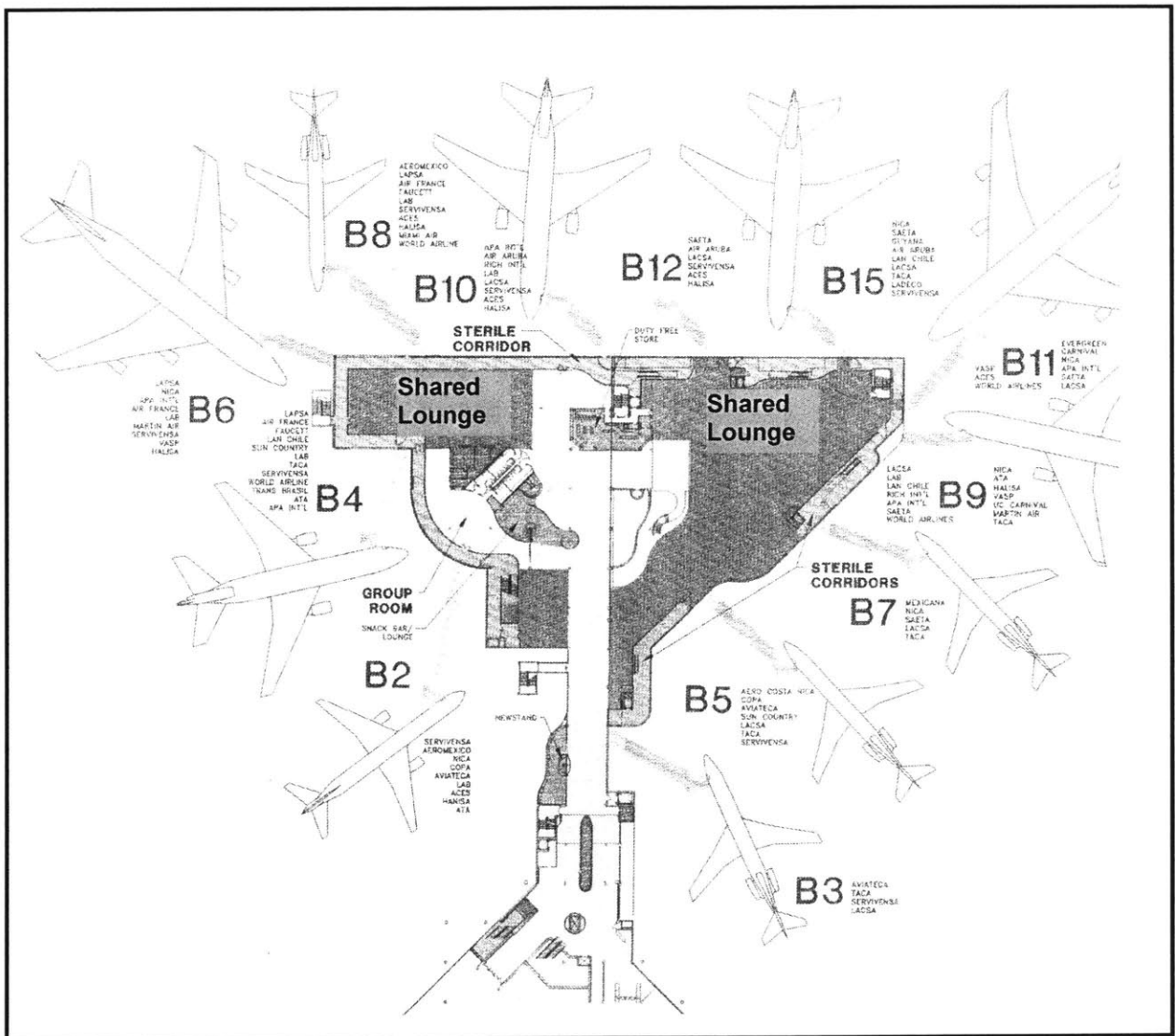


Figure A1.2. Shared Departure Lounge at Miami/International Concourse B

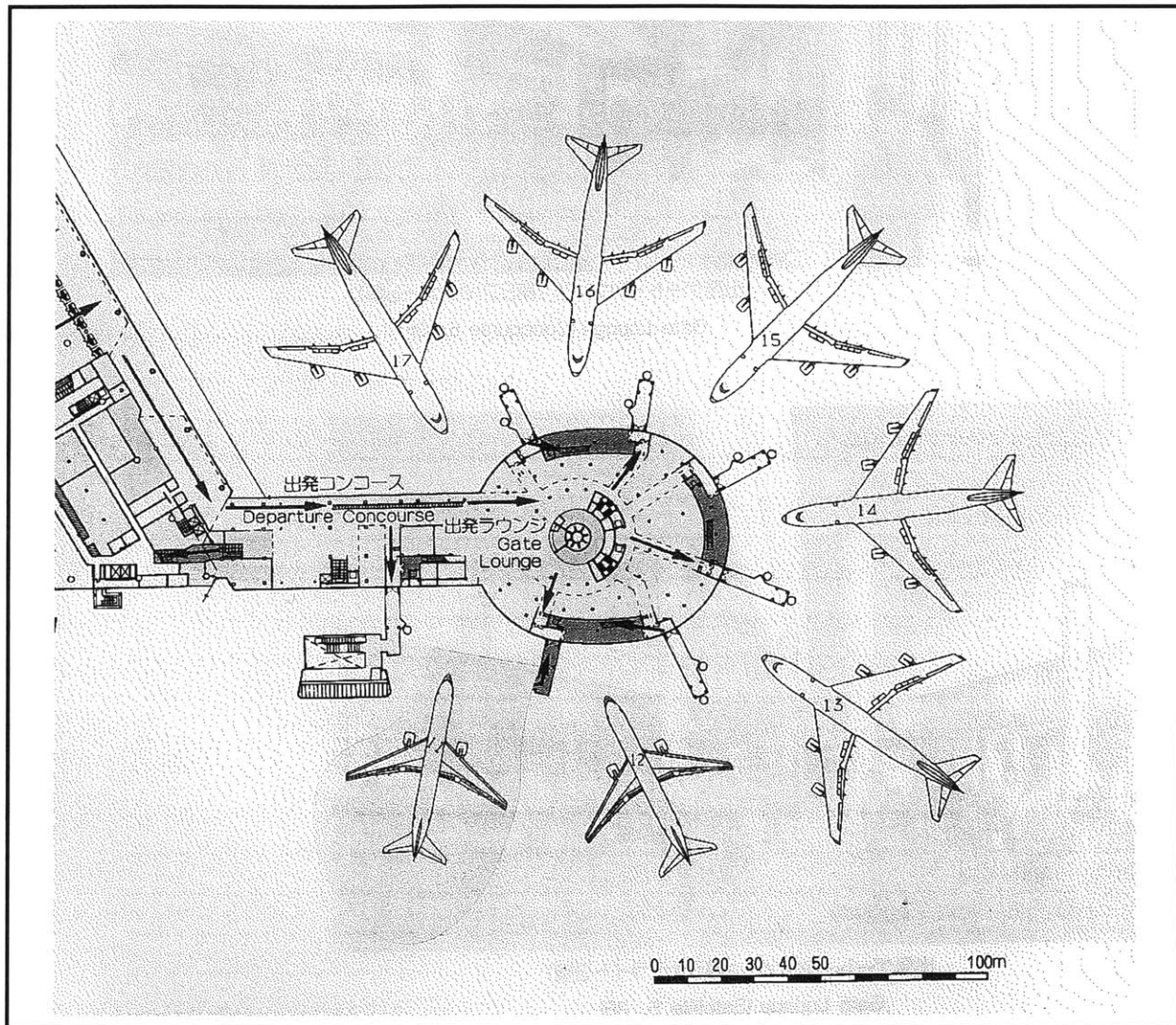


Figure A1.3. Shared Departure Lounge at Tokyo/Narita

Appendix II: Documented International/ Domestic Swing Gate Systems

AIRPORT	YEAR	# SWING GATES
North America		
Atlanta/Hartsfield	1994	~24
Calgary, Canada	2004	
Dallas/Fort Worth	1993	~15
Dallas/Fort Worth	plan	23
Denver/International	1995	2 - 4
Ft. Myers, FL	1993	
Las Vegas/McCarran	1991	3
Los Angeles/International	1996	
Los Angeles/International	1985	
Miami/International		60+
Montreal, Canada		
Orlando/International		
Orlando/Sanford	2000	3
Toronto, Canada		
Toronto, Canada	plan	14 - 16
Australasia		
Adelaide, Australia	2001	~10
Brisbane, Australia	plan	
Cairns, Australia	plan	
Christchurch, New Zealand	plan	
Darwin, Australia	plan	
Hobart, Australia	plan	
Perth, Australia	plan	
Wellington, New Zealand	1999	3
Asia		
New Bangkok, Thailand	plan	
Kuala Lumpur, Malaysia	1998	
Osaka/Kansai	1994	6
Chubu/Central Japan	2005	
Africa		
Cairo, Egypt	existing, plan	15
Mombasa, Kenya	1995	
Europe		
Birmingham, U.K.	1990	10

NORTH AMERICA

Atlanta/Hartsfield

Concourse E 1994

Source: Turner and Associates Architects and Planners. (Atlanta, GA, USA) (31 Jan. 2000)
"Concourse E" <http://www.turner-olh.com/concourse-e.htm>

“One of the most unique features is the functionality for passengers in this massive complex. Escalators to the third floor of the facility immediately transport arriving international passengers, where they are directed to the central immigration processing area. They then proceed down secured escalators to the first floor for baggage and customs inspection. Departing international passengers have no contact with new arrivals. Instead, they are directed up escalators to the second floor where additional retail shops, concession areas, airline information counters and gate waiting areas are located.”

Source: City of Atlanta, Department of Aviation. (31 Jan, 2000) “Hartsfield International Airport, Physical Facilities Inventory”
<http://www.atlanta-airport.com/physicalfacilities.html>

“Concourse E services international departures and arrivals and is served by ALM, Antillean Airlines, Aeromexico, Air Jamaica, Austrian Airlines, British Airways, Cayman Airways, Delta Air Lines, Japan Airlines, KLM Royal Dutch Airlines, Korean Air, Lufthansa, Malev Hungarian, Sabena, Swissair, and Varig. It has 27 gates, with capability for expansion to 34. Concourse E is designed for dual use, domestic as well as international....On June 1, 1997, Delta initiated limited domestic service at Concourse E. The facility is equipped with automatic passenger flow control at each gate to direct international passengers to federal inspection and customs areas or to direct domestic passengers to the main passenger level.”

Calgary, Canada

Concourse D, 2004

Source: Ellis-Don Construction (Calgary, Canada) (Jan 31, 2000) "Ellis-Don Calgary Airport" <http://www.ellis-don.com/Market/Civil/calair.html>

"Presently there are four gates at this location serving shuttle and domestic passengers. Future construction will see outward building expansion which will allow the existing gates to become swing gates (i.e. provisions will be made to process trans-border passengers also). This will consist of a three storey structure with baggage claim areas, airline ramp services and public circulation on the Arrivals level. On the Departure Level will be holdroom seating areas (shuttle and trans-border), retail units, domestic check-in counters and related check-in conveyors. The Mezzanine will see a sterile corridor linking the future international inbound passengers from D-Stage Pier 1 and inbound trans-border passengers. Included in this expansion is the demolition of three fixed passenger gates, three new Apron driven bridges and relocation of fuel lines."

Dallas/Fort Worth

Terminal 2E, 1993

Source: Corgan Associates, Inc. (Dallas, TX, USA) (31 Jan, 2000)

“American Airlines Eastside Expansion Dallas/Fort Worth International Airport”

<http://www.corgan.com/projects/dfw2e.html>

“American purchased the rights to use gates 5 through 10 at Terminal 2E from Continental Airlines. In addition, American Eagle, the affiliated commuter airline, moved their operations to a new commuter terminal making gates 1 through 4 available for jet operations. This enabled American to develop a unified fifty-seven jet gate operation. Gates 1 through 9 were renovated for mid and narrow-body aircraft. Gates 10-23 accommodate wide-body aircraft. Concourses were refurbished to American's systemwide standards and were provided with departure lounges, concessions, and restrooms to support the increased traffic generated by the new gates. In addition to the remodelling of gates 1 through 10, the exterior wall facing the ramp was demolished and rebuilt thirty feet further airside at gates 9 through 23. These are domestic/international ‘swing’ gates. This provides more departure lounge and concourse area, and creates a third level which is used for international in-transit passengers. This new design allows American to concentrate functions and operate more efficiently while providing customers a clearer orientation in what has now become a unified terminal.”

Proposed Terminal D

Source: Dallas / Fort Worth International Airport (31 Jan, 2000) “Capital Development Program” <http://www.dfairport.com/development/cdp>

“The Terminal D project consists of design and construction of a new consolidated international terminal located in the “D” area of the Central Terminal Area. The proposed 23-gate terminal

facility would have “swing” capability for both international and domestic service.... By consolidating all international operations (currently handled in Terminal A, Terminal B and Terminal E) into a single world-class terminal, Dallas/Fort Worth International Airport will be better equipped to handle the international traffic that exists today and the growth that is projected for the future. Moreover, the consolidation of all international flights into this single terminal will free-up existing gates which will accommodate American Eagle’s regional jet operations. In essence, the unoccupied gates will allow the regional airline to move existing hardstand activities to a terminal with loading bridges. Logically, the consolidation of this international traffic into one facility would provide for a more efficient and effective ability to handle international traffic as DFW Airport positions itself as an international gateway. Moreover, the new terminal will address a variety of objectives and key issues, including: Efficient operating environment – The terminal design will provide maximum flexibility for airline operating efficiency.”

Source: Dickinson, J. (1999, Nov., 1) “On the go: What’s needed to avoid gridlock as the Metroplex grows,” Dallas Business Journal, p. 17B.

“The two terminals, both on the west side of the airport and costing \$692 million, would include an upgraded Terminal D to primarily serve American Eagle Airlines, and a new Terminal F to serve international carriers. The international terminal, serving every carrier with overseas flights, will encompass 1.4 million to 1.8 million square feet, Cox said, double the size of Terminal A, which is currently the largest terminal at the 18,000-acre airport. The new terminal will also feature ‘swing gate’ capacity, allowing it to serve domestic carriers when international flights aren’t at capacity.”

Denver/International

Source: Evans, G. (1995) "The New Denver Airport," Transportation Research Circular, No. 445, pp. 6–12.

"One special feature of the terminal is the way international arriving passengers are handled. Passengers come off the aircraft and stay high within Concourse A, moving through the central core portion of the building. The international passengers will use the upper level of the pedestrian bridge linking Concourse A with the terminal building and then go down two levels for processing through the FIS facility. That was a critical master planning decision, and there are some pros and cons. DIA is the only airport in the world where aircraft will pass under a pedestrian bridge. This was carefully negotiated with the FAA. On opening day DIA will have the capacity for two widebody international flights on the north side of Concourse A. This space can also be used for four domestic gates, if desired."

Source: Suehiro, J., McCagg, E., and Seracuse, J. (1992) "The Design of Airside Concourses," A New International Airport. New York: American Society of Civil Engineers, p. 207-216.

"As needed, international gates can also be used as domestic gates. Specially designed nodes, which are attached to the face of the concourse, provide flexible circulation to various levels of the concourse to separate passenger flows. Two aircraft loading bridges are attached to each node to achieve total flexibility of gate use. A single widebody aircraft or two narrowbody aircraft may be parked at each of the four nodes. Circulation within the nodes can be separated for simultaneous domestic and international operations."

Ft. Myers, FL (Southwest Florida International Airport)

International Terminal, 1993

Source: Board, P. and Colcord, E., (Jan 31, 2000) "A History of Aviation in Lee County"
<http://www.swfia.com/aboutairport/history/history.html>

"In November of 1992, construction began on a 55,000-square foot terminal addition which will house a new Federal Inspection Station and additional passenger ticketing and waiting areas. Not only will the facility increase the number of passengers to be handled by customs from 150 to 400 per hour, it also will allow the dual use of existing gates for both international and domestic flights."

Las Vegas/McCarran

Terminal 2, 1991

Source: Clark County, NV Department of Aviation (Jan 31, 2000) "Terminal 2 Fast Facts"
<http://www.mccarran.com/Terminal/Term2FastFact.htm>

Terminal 2 is used for international arriving flights (scheduled and charters) and domestic charter flights. Three of the eight gates are equipped with glass-enclosed sterile corridors which can be used to route international arrivals into the adjacent FIS facility.

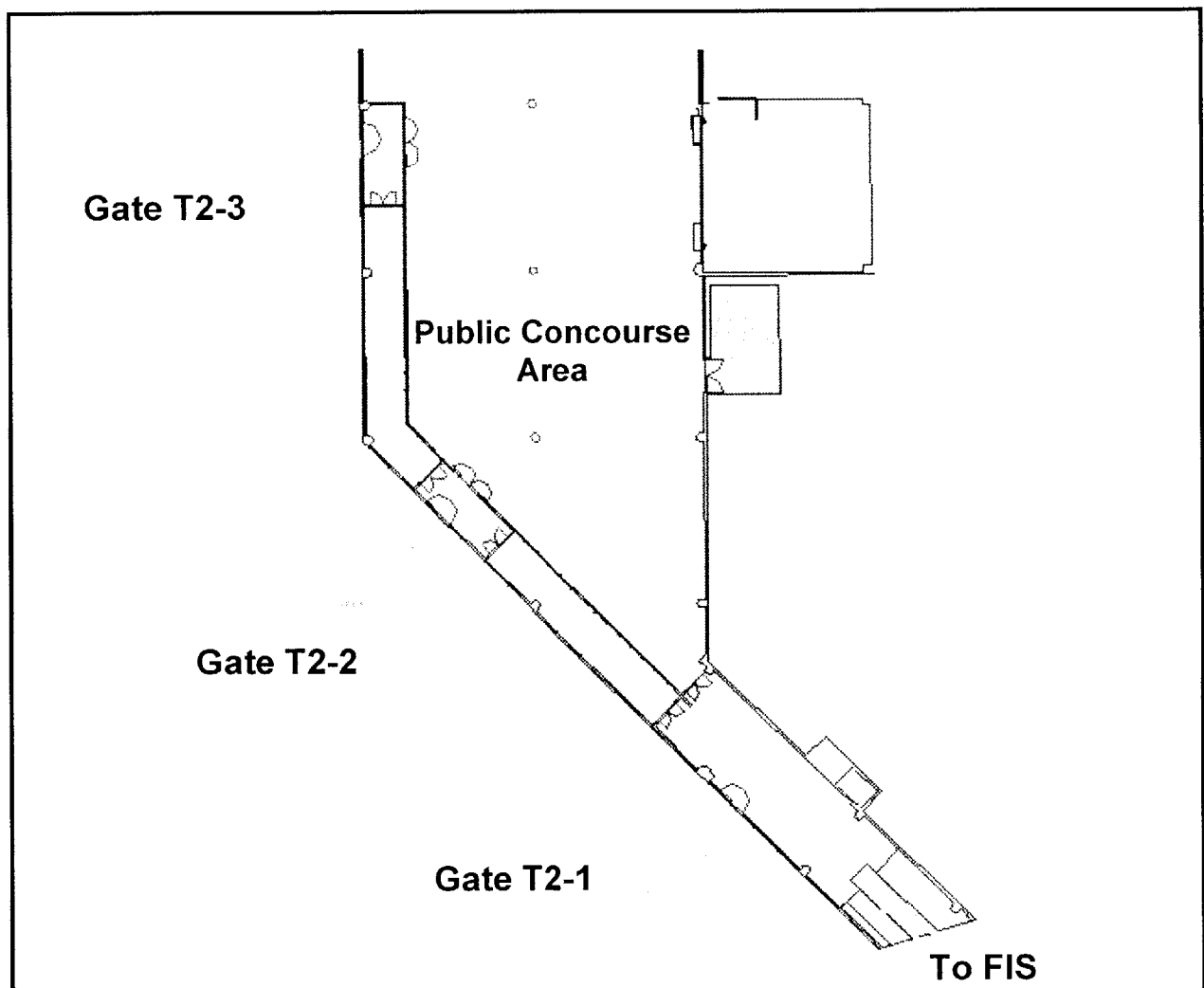


Figure A2.1. International/Domestic Swing Gates at Las Vegas/McCarran

Los Angeles/International

Terminal 6, 1996

United Airlines operates international / domestic swing gates in Terminal 6 at LAX.

Source: Los Angeles World Airports (Jan 31, 2000) "History Search Page"
<http://www.lawa.org/laxhistory/lax.htm>

July 1994 "UAL to build federal inspection facility. United Airlines announced plans to construct a federal inspection service facility along with other improvements, in Terminals 6 and 7 at LAX. When completed, the construction will ease congestion in the Tom Bradley International Terminal and increase efficiency in UAL's passenger handling."

Source: "Custom Help at LAX," (1996, May, 26) Los Angeles Times, p. L-3.

"Meanwhile, United Airlines this summer will open its own customs-clearance facility, the fourth at the airport. The new 90,000-square-foot underground facility between Terminals 6 and 7, will be able to process up to 700 travelers an hour; it can now take 2 _ hours to go through customs checkpoints at the Tom Bradley International Terminal....No one has it much worse than United passengers, who must deplane via a portable staircase, catch a bus to the Bradley Terminal, go through customs and then, if they are connecting to domestic flights, take a shuttle back to the United terminal. The new \$51-million facility centralizes the whole process for United passengers, while taking some of the load off the three other immigration and customs centers at the airport."

Source: American Association of Airport Executives (1996, Jun, 26) "United Opens LAX Facility," Airport Report Express, Vol. 6, No. 52.

"United Airlines Monday unveiled its new \$51 million Federal Inspection Services (FIS) facility at Los Angeles International Airport, a 90,000-square-foot facility that is intended to handle all of the airline's immigration, customs and baggage processes for its international passengers. The underground facility allows both terminals six and seven to feed into the international service area. The new facility will be able to accommodate three 747-400s simultaneously by providing space for 36 federal inspectors. The area has three major baggage carousels."

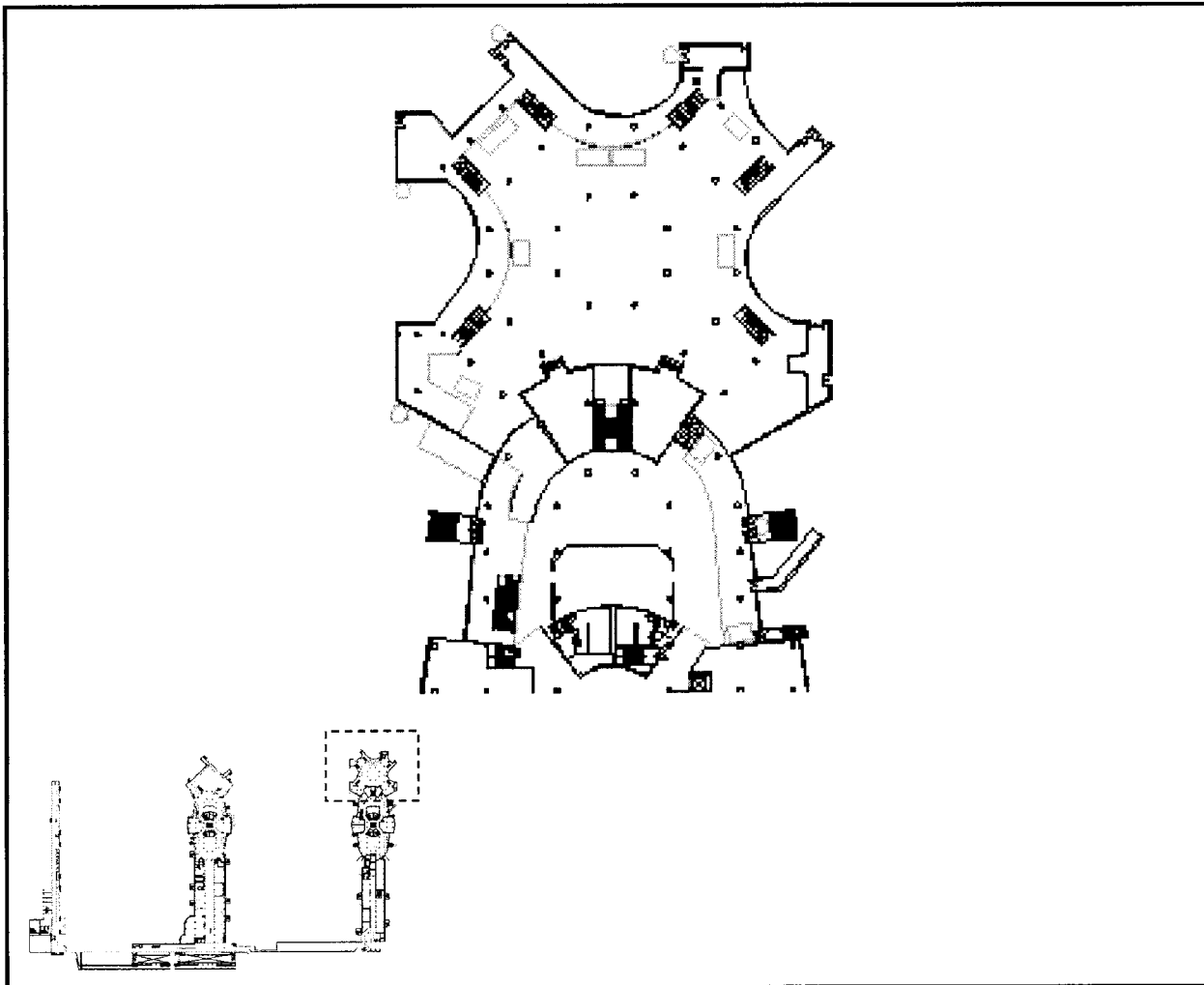


Figure A2.2. International/Domestic Swing Gates at LAX, Terminal 6

Miami/International

Concourses B, D, E, F, Remote Terminal

Source: Landrum & Brown (1994) MIA Master Plan Update: Technical Report. Prepared for Metropolitan Dade County, Florida, Aviation Department.

“Nearly all gates in concourses B, D, E, F and the Remote Commuter Terminal are equipped for use by both domestic and international flights. FIS services are provided in two areas of the terminal building. One FIS area is a split level operation located in the main body of the terminal building on the first and third floors below and above the entrance to Concourse E. The third floor of the Concourse E FIS facility is connected to the various international gates via sterile walkways and houses Immigration and Naturalization Service (INS) and Public Health Service (PHS) functions. The third floor area is connected with the first floor Concourse E FIS area via elevators and escalators. The first floor portion of the Concourse E FIS area accommodates United States Customs Service (USCS) and Animal and Plant Health Inspection Service (APHIS) functions and includes baggage claim, waiting lounges, office and inspection space, and other related space. The terminal building’s second FIS area is also located at the third level but near the entrance to Concourse B. The Concourse B FIS facility is located on a single floor and currently has sterile access to Concourse B. It will eventually be tied into the same sterile corridor network utilized to access the Concourse E FIS area. The Concourse B FIS area includes all functional space needed to process passengers plus additional waiting lobby and meeting/training space.”

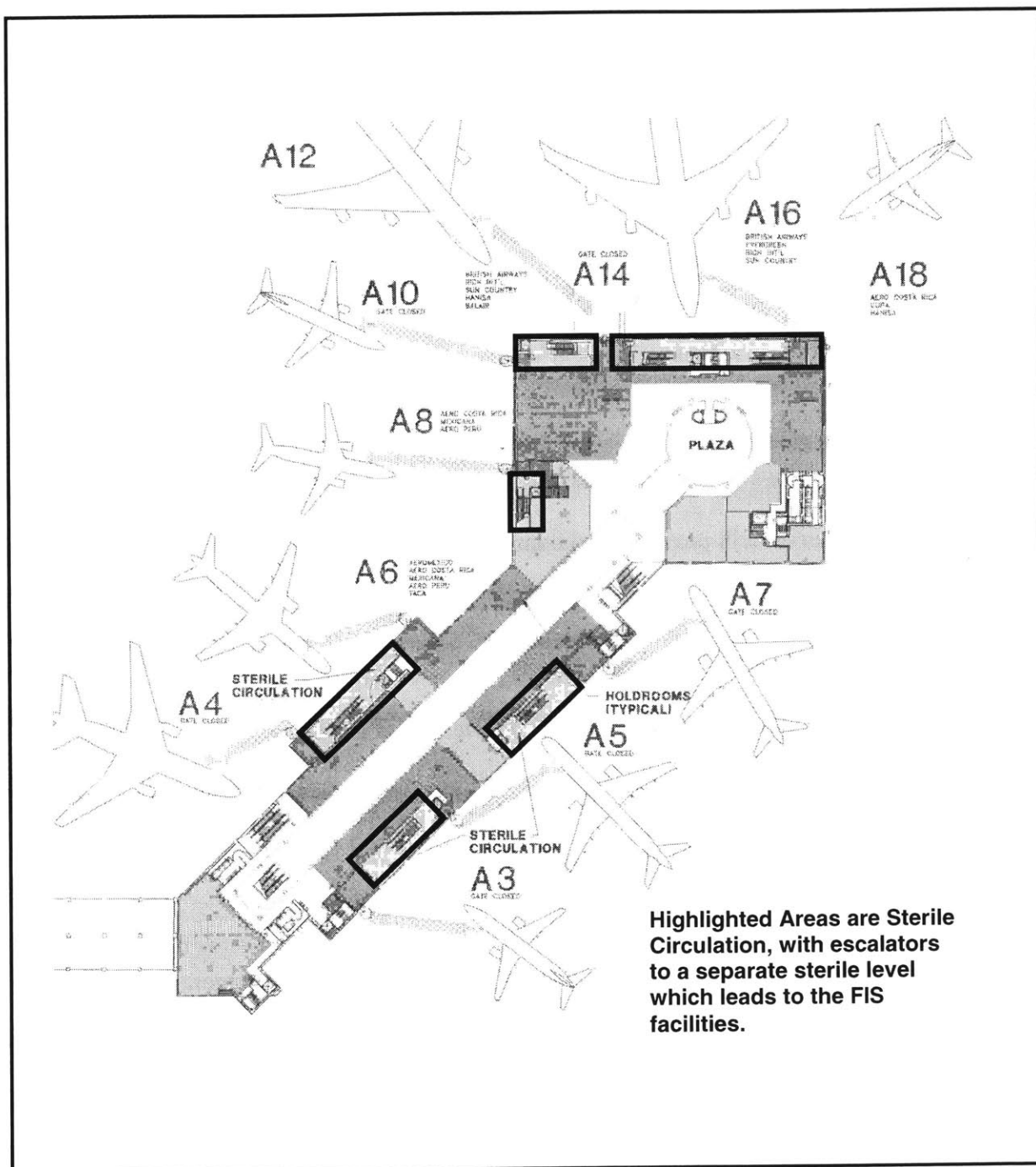


Figure A2.3. International/Domestic Swing Gates at Miami/International, Concourse A

Montreal, Canada

Source: Aeroports de Montreal (May 3, 2000) "Development at Montréal International Airport - Dorval enhancing Montréal's competitiveness" http://www.admtl.com/administration/en/4_nouvelles/revues_de_presse/06-05-1999-3-e.shtml

"The Chairperson of the Board and interim Chief Executive Officer of Aéroports de Montréal, Ms Nycol Pageau-Goyette today announced that the next phase of development at Montréal International Airport - Dorval was scheduled for the northwest quadrant and that, following extensive consultation with carriers, development would take the form of multifunctional equipment and infrastructure.

"To enhance Montréal's competitiveness, the next stage in the development of Montréal International Airport - Dorval will provide for the integrated operations of our many partners with a view to reducing connection time and passenger walking distance, both important criteria in the eyes of the carriers," stated Ms Pageau-Goyette.

Given the rapidly changing face of the air transport market and the growing number of carrier alliances, plans for subsequent development of the Dorval passenger terminal have been completely revisited since they were first announced 1996....

The next phase of the expansion plan drawn up for Montréal International Airport - Dorval will allow for the servicing of international and transborder flights from the same finger, which will constitute a major asset for Montréal. This finger will include: The addition of multifunctional gates and the transformation of a number of others."

Orlando/International

Source: Greater Orlando Aviation Authority (Jan 31, 2000) "Orlando International Airport – Planning" <http://www.state.fl.us/goaa/planning/planning.htm>

"North Terminal improvements totaling approximately \$395 million are currently being made and should be completed in 2001. These include the design and construction of Airside 2 (the fourth airside, located to the northeast of the existing terminal), improvements to the existing landside terminal, an AGT system to connect the airside to the terminal, expansion of the swing gates allowing international or domestic operation from a single gate area, a north crossfield taxiway to allow aircraft to cross the airport from east to west without having to taxi south of the terminal, and a new FAA air traffic control tower."

Source: Ward, C. (1999) "Orlando International Expands," Janes Airport Review, Vol. 11, No. 8.

"The South Terminal will serve both domestic and international travellers, but is being designed to accommodate the needs of the expanding international market. Orlando International served nearly 27.7 million international passengers in 1998, a 3.9% decrease from 1997, but projections are for growth. The initial 12 gates in the South Terminal will be primarily international, Westhart says. 'We're designing everything to be swing-gate capable. It will serve our international passengers better and put them more on an equal footing with the domestic passenger as far as convenience and ease of movement.' "

Orlando/Sanford

Domestic Terminal, 2000/2001

The new domestic terminal developed and managed by TBI US, an American subsidiary of the UK based airport operator TBI plc.

Source: Orlando Sanford International Airport (1999) "Sanford Airport Authority Approves 30-Year Management Contract for Orlando Sanford's Domestic Terminal," press release.

"...to provide greater flexibility and service to existing international carriers, three of the seven gates will have the ability to be 'dual use' to service both domestic and international flights."

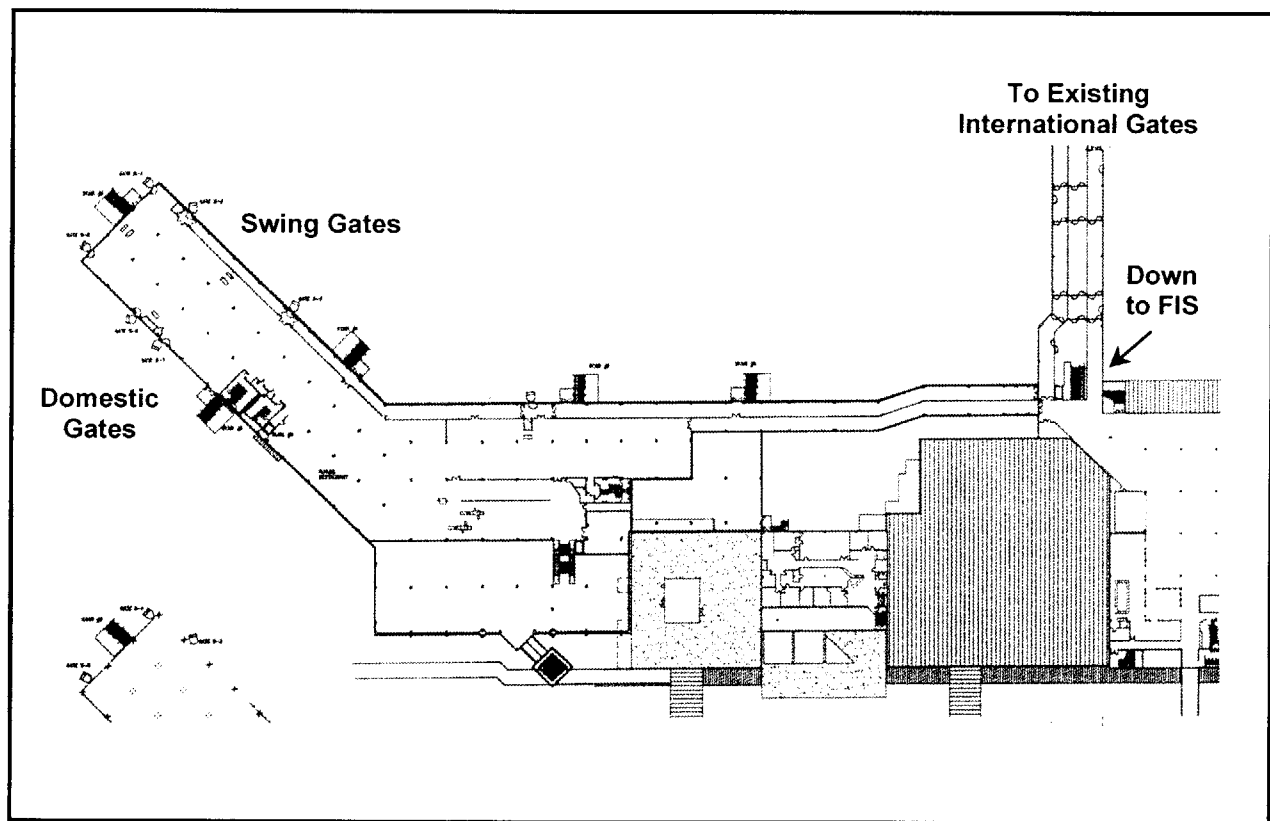


Figure A2.4. International/Domestic Swing Gates at Orlando/Sanford

Toronto, Canada

Toronto/Pearson has swing space capability, in which entire portions of the terminal, including gates, seating and circulation space, and baggage claim space, can be allocated to international or domestic operations. The following quote discusses the planned new terminal development.

Source: Greater Toronto Airport Authority (Apr 18, 2000) “The Airport Master Plan Summary Report” http://www.gtaa.com/publications/masterplan/GTAA_Sum_chpt4_PASSENGER_TERMINALS.pdf

“Pier E will serve primarily domestic operations, with the flexibility to provide domestic/transborder swing gates. It will provide 14 bridged gates. Pier F is the largest pier with 31 bridged gates and is located at the mid-point of the central processor. The large head of the pier is designed to accommodate international operations. It provides the holdroom area necessary to support the simultaneous gating of several widebody aircraft and a large retailing area catering to international passengers. Transborder operations will be accommodated along each side of Pier F and between Piers E and F.

During various stages of terminal construction, existing gates on Terminals 1 and 2 will be removed or deactivated due to adjacent demolition/ construction. To ensure that there is no shortfall of gates during the terminal development process, a temporary ten-gate holdroom terminal may be constructed in the infield to accommodate domestic, transborder and international traffic.

Development during the 2005-2015 time period calls for the expansion of the New Terminal central processor and parking garage, construction of Pier G and highway access and on-airport road-way improvements. This phase is illustrated in Figures 19 and 20. With 17 bridged gate positions, Pier G will accommodate both transborder and international operations,

and like Pier F, will have international gates located primarily at the head of the pier, with transborder gates located on either side of the pier's length between the head and the processor.

At the end of this phase, the New Terminal, Terminal 3 and the Infield Holdroom Terminal will together provide 112 bridged gates and will have the capacity to accommodate 39-45 million passengers annually. It is estimated that the airport will be able to handle approximately 400,000 passengers per gate per year at accept-able levels of service. This is due to improved gating efficiencies and space allocation within the New Terminal."

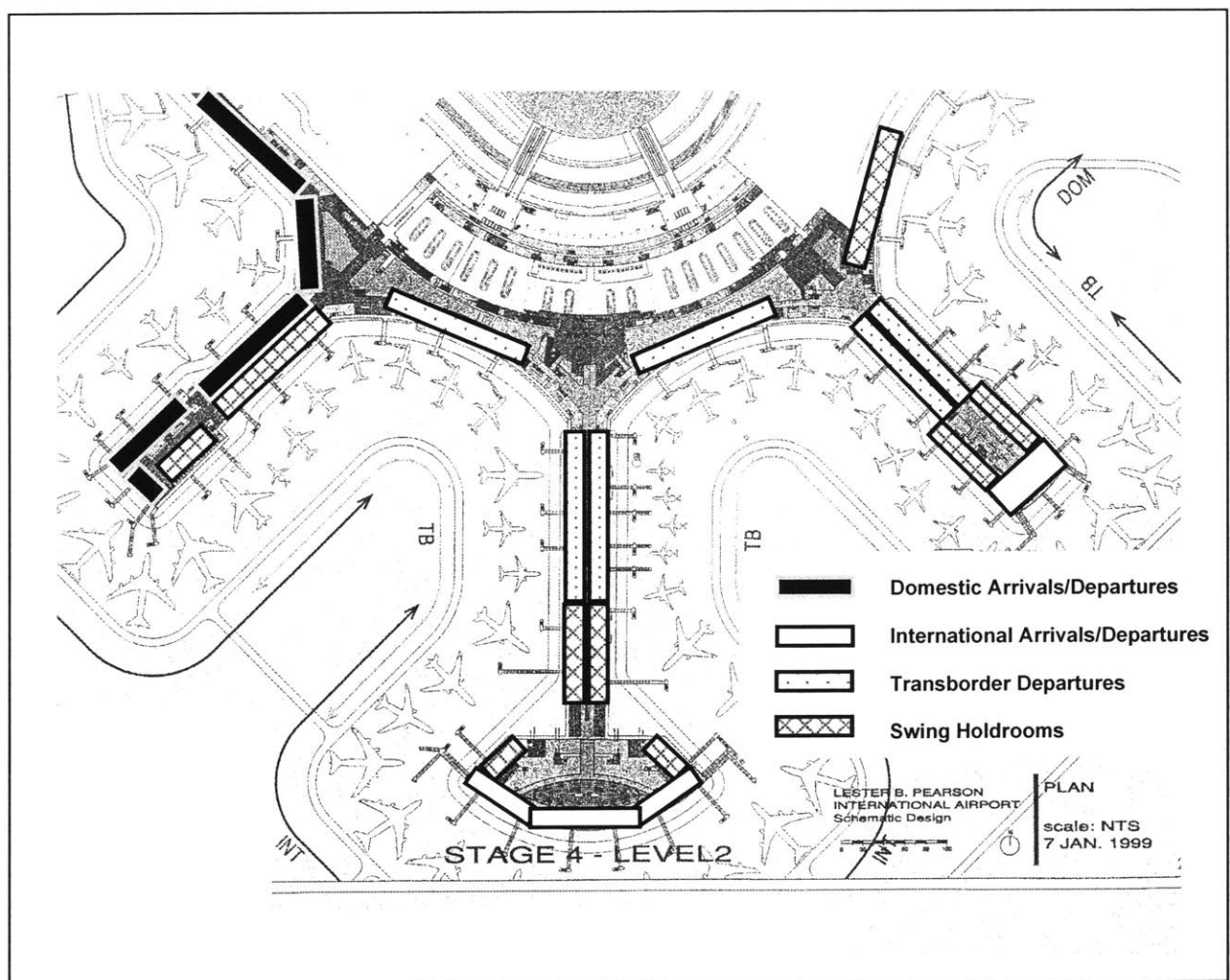


Figure A2.5. International/Domestic Swing Gates planned at Toronto/Pearson

AUSTRALASIA

Adelaide, Australia

Multi-User Integrated Terminal, future

Source: South Australian Government, Office of the Premier (31 Jan 2000) "Airport Upgrade for Adelaide" http://www.ministers.sa.gov.au/premier/highlights/drawing_board/airport_upgrade.html

"The South Australian Government views the upgrading and integration of the domestic and international passenger terminals at Adelaide Airport as a fundamental component for the state's economic development, to re-position the Adelaide Airport infrastructure to international standards and provide an appropriate gateway image for South Australia.

Adelaide Airport Limited (AAL) is committed to the integration of the terminal facilities at Adelaide Airport and as such has developed a proposal for a Multi User Integrated Terminal (MUIT) facility. AAL's terminal design is an enhancement of terminal plans developed by the State Government in conjunction with Qantas and Ansett and then progressed by the FAC in the form of the MUIT.

The \$180m facility, scheduled to be completed in early 2001 is a new two storey terminal building which will be constructed adjacent to the current international terminal. The proposal features 10 aerobridge gates capable of accommodating the range of aircraft using Adelaide Airport both domestically and internationally. The terminal will be accessed through a raised road running its entire length at the first level. All gates will have aerobridges to provide cover for passengers when walking between aircraft and terminal buildings.

The State Government has been working closely with AAL to facilitate the approvals process required for the development of the integrated terminal facility. AAL is hopeful of starting ancilliary work on the terminal site early this year with the major construction work due

to start around June, 1999. The new terminal will be the first major terminal development flowing out of the sale of the Australian Government's airports. The integrated terminal facility will be purpose built for the current and emerging aviation environment wherein international, domestic and regional services are closely integrated and airlines strive to make seamless transfers between the three levels the norm. The use of swing gates will further accentuate the 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. The MUIT will be a state of the art terminal coordinated by the one operator, allowing efficiencies of operation and consistency in service and will be the first of its kind in Australia. As such, Adelaide Airport has the opportunity to be used as the model for future airport design in Australia.”

Brisbane, Australia

Source: Brisbane Airport Corporation (Apr 18, 2000) "Brisbane Airport Master Plan"
<http://www.brisbaneairport.com.au/corp/master.asp#103596>

"Terminal Development:

Efficient user-friendly passenger terminals will be provided to accommodate passenger traffic which is expected to increase threefold between 1998 and 2108. Brisbane Airport features two separate passenger terminals. The Domestic Terminal Building (DTB), located in the Central Terminal Area, processes presently 75% of the total traffic, while the International Terminal Building (ITB), situated in the Southern Terminal Area, serves the remaining 25% of the traffic.

Future terminal development will be focused in the Central Terminal Area in which the existing Domestic Terminal is located. However, depending on demand, flexibility will be retained to expand the International Terminal Building. In order to facilitate international/domestic transfer it is expected that some international traffic will be handled at the Central Terminal Area in future and terminal buildings will be expanded and modified as necessary to facilitate this traffic. Terminal development will be integrated with commercial development and provide safe and convenient facilities for airlines and passengers."

Cairns, Australia and Christchurch, New Zealand

Source: “Improving Future Terminals” (1998) World Airport Week, Vol.5, No. 8.

“An Australian airport planning firm is encouraging its clients to take a hard look at how airport terminals are designed and built in the future. Through the use of swing gates and proper terminal design, Airplan of Australia advocates combining international and domestic terminals for more efficient land utilization, as well as providing better passenger services. Calling the concept UnCUT, for universal common use terminal, Airplan recently published a paper outlining the advantages and future possibilities for airports employing a universal common-use terminal.

The idea of combining international and domestic terminals isn't new. Keith Thompson, vice president of HNTB, a Kansas City architectural and engineering firm, said Los Angeles International Airport (LAX) has used a universal common use gate concept since 1985. What is new is that more and more airports are implementing the concept and Airplan wants that trend to continue. Graeme Thompson, senior terminal planner for Airplan, said Cairns International Airport (CNS) and Christchurch International Airport (CHC) intend to incorporate UnCUT concepts in their future expansion plans. Thompson added that those airports with roughly equal numbers of domestic and international passengers would see the greatest benefits of common-use terminals.”

Darwin, Australia

Passenger Terminal, future

Source: Northern Territory Airports Pty Ltd. (Jan 31, 2000) "Darwin Master Plan Executive Summary" <http://www.ntapl.com.au/darwin/dar2.htm>

"The terminal complex will be expanded and configured as a multi-level terminal in the terminal reserve....The terminal will be accessed from a single level passenger loop road. The international gates will be concentrated on the western end. The domestic gates will be expanded on the eastern end. The current concept proposed primary concourses arranged in a linear configuration with aircraft parking positions on one side. The final terminal design may vary to take account of market conditions and stakeholder needs.

International/Domestic Swing Gates: To maximise terminal capacity and provide more effective land use, a portion of the gates will be designed to alternately accommodate international and domestic passenger operations at the same gate. These gates are commonly referred to as swing gates. This results in the to serve more aircraft with fewer gates than in a dedicated gate scenario."

Hobart, Australia

Source: Airplan Airport Planning Pty Ltd (18 April, 2000) "Hobart Terminal Study"
<http://www.airplan.com.au/flyer/phasetwo.htm>

"The Federal Airports Corporation has appointed Airplan to undertake a Terminal Review Study of Hobart's Domestic and International terminals preparatory to the Airport being offered for sale in the next round of airports privatisation.

The two terminals virtually adjoin, and whilst the international facilities are of more recent construction they are relatively under utilised with the principal uses being scheduled services to and from New Zealand, and charter services from Singapore.

Airplan's study has involved extensive consultation with the domestic carriers, Qantas and Ansett, together with the international airlines, Government departments and other key stakeholders. The preferred option resulting from the study is for a combination of the two terminals, and the creation of a common user facility as the first step towards improved utilisation."

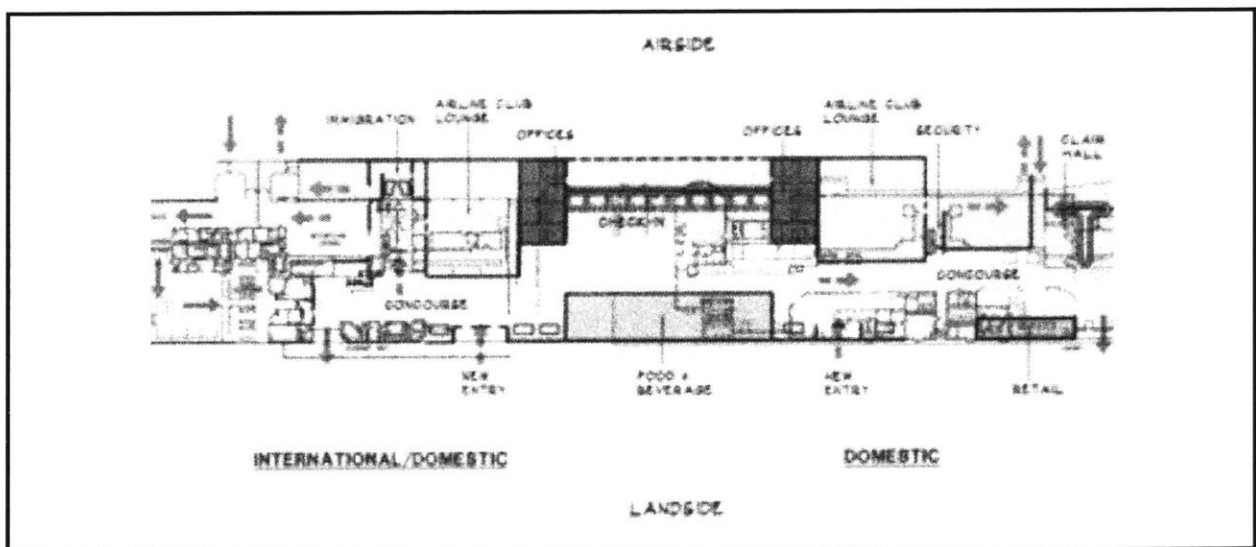


Figure A2.6. Tentative Plans for Swing Gates at Hobart, Australia

Perth, Australia

Source: Westralia Airports Corporation (April 18, 2000) “Perth International Airport Draft Master Plan (Executive Summary)” <http://www.perthairport.net.au/airplan/master.pdf>

“Land Use Planning and Related Benefits:

The Draft Master Plan (DMP) envisages consolidated domestic and international terminal operations in a terminal located in the vicinity of the existing International Terminal Building. This consolidated facility is expected to enhance user convenience and improve the efficiency and cost-effectiveness of both airline and airport activities. With future terminal activity consolidated, the existing domestic terminal area will become available for redevelopment. This area has potential for aviation-related, institutional and commercial opportunities.

Airport Systems Overview:

The airport layout plan focuses on the airport systems required both in 2018 and at the airport’s ultimate development capacity potential....Forecasts for 2018 indicate that up to 17 B747-size aircraft parking positions will be needed to accommodate international flights. Forecasts for domestic operations indicate that up to 29 aircraft parking positions ranging in size from B747- to B737-size aircraft will be needed. The existing domestic terminal area will be redeveloped to accommodate smaller regional airlines and general aviation activities. The plan also reserves the option to continue development of the existing domestic terminals in their present location should Ansett and Qantas choose to remain there until the expiration of their domestic terminal leases.”

Wellington, New Zealand

Opened 1999

Source: Airplan Airport Planning Pty Ltd (18 April, 2000) “Wellington Terminal Opens”
<http://www.airplan.com.au/airplan-press-wterminal.html>.

“The new terminal at Wellington Airport has opened for business. At a ceremony on 15 July, New Zealand Prime Minister, Jenny Shipley, officially opened the new NZ\$42 million terminal....As Airport Planning Consultant, Airplan was responsible for the concept planning and functional design of the new terminal which includes a series of innovative features. These include: a single integrated terminal combining regional, domestic and international operations, ‘swing gates’ which enable international gates to be easily converted for use by domestic operations and vice-versa, and ‘swing’ baggage claim facility that can be utilised for both international and domestic operations.”

Source: Airplan Airport Planning Pty Ltd (1999) “Wellington Airport’s New Terminal,” press release.

“A centralised terminal providing facilities for regional, domestic and international passengers represented a move away from conventional practice of segregated facilities. The new terminal offers a single check-in hall, centrally located retail ‘street’ and food and beverage facilities, with expansive views of the aircraft movement area and surrounding coastal environment. This concentration provides not only a focal point and convenience for passengers and friends but also ensures that maximum exposure to retail and other facilities is maintained. The arrivals area is also a common facility, with passengers on international flights accessing the area from the Customs Area. Car hire and other facilities are offered at this level, together with easy access to the retail and food and beverage area above.

Swing Gates:

Airplan has been instrumental in the introduction of swing gates in airport terminals in New Zealand and overseas. The principle behind a swing gate is to provide a physical arrangement which allows an aircraft gate to be used, say, for an international flight, immediately followed by a domestic flight, and vice-versa. This facility can greatly increase gate utilisation, especially at those airports, such as Wellington, where domestic and international peaks do not coincide. As swing gates influence the functional layout of the terminal and the apron, consideration must be given to their provision at an early stage in the planning process. At Wellington, three swing gates have been provided in the North Pier.

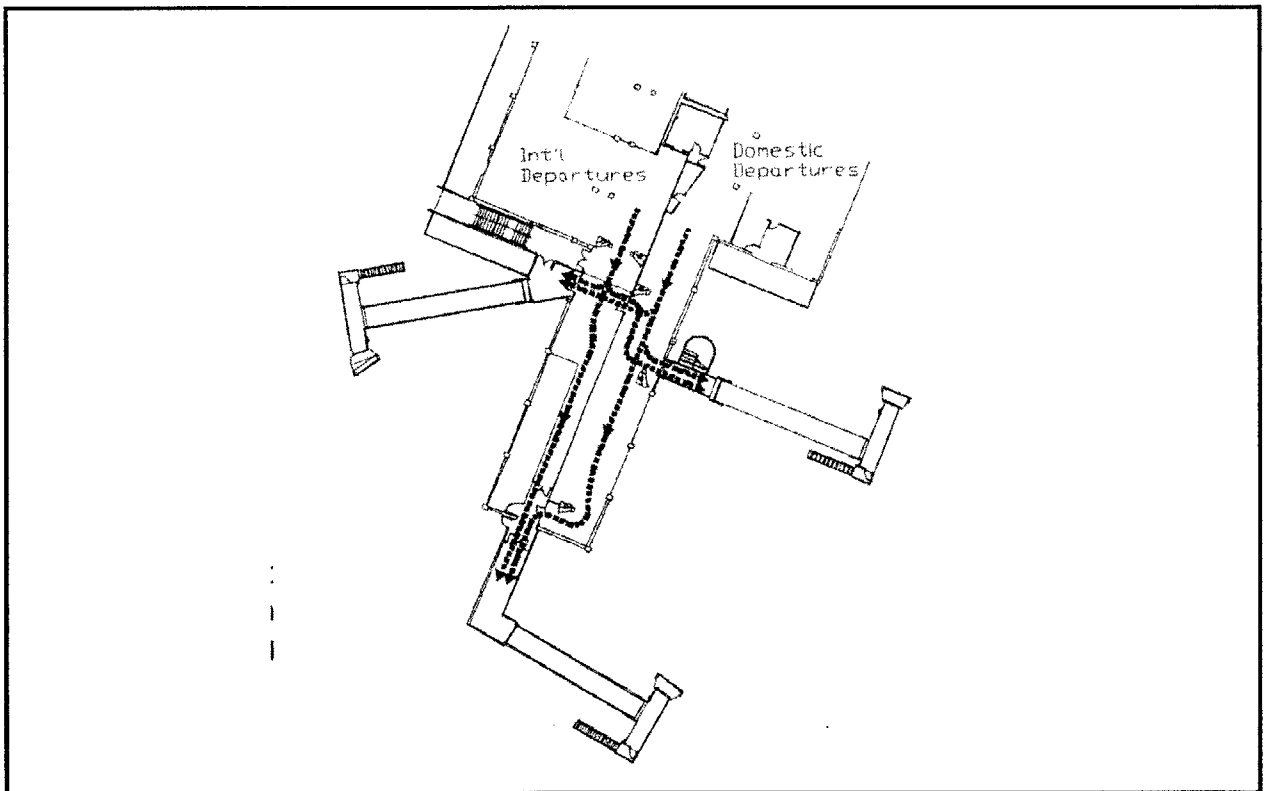


Figure A2.7. International/Domestic Swing Gates at Wellington, New Zealand

Swing Baggage Claim Facilities:

The swing gate theme is carried though to the international baggage reclaim facility which can be utilised for both international and domestic operations, through the provision of an operable wall.”

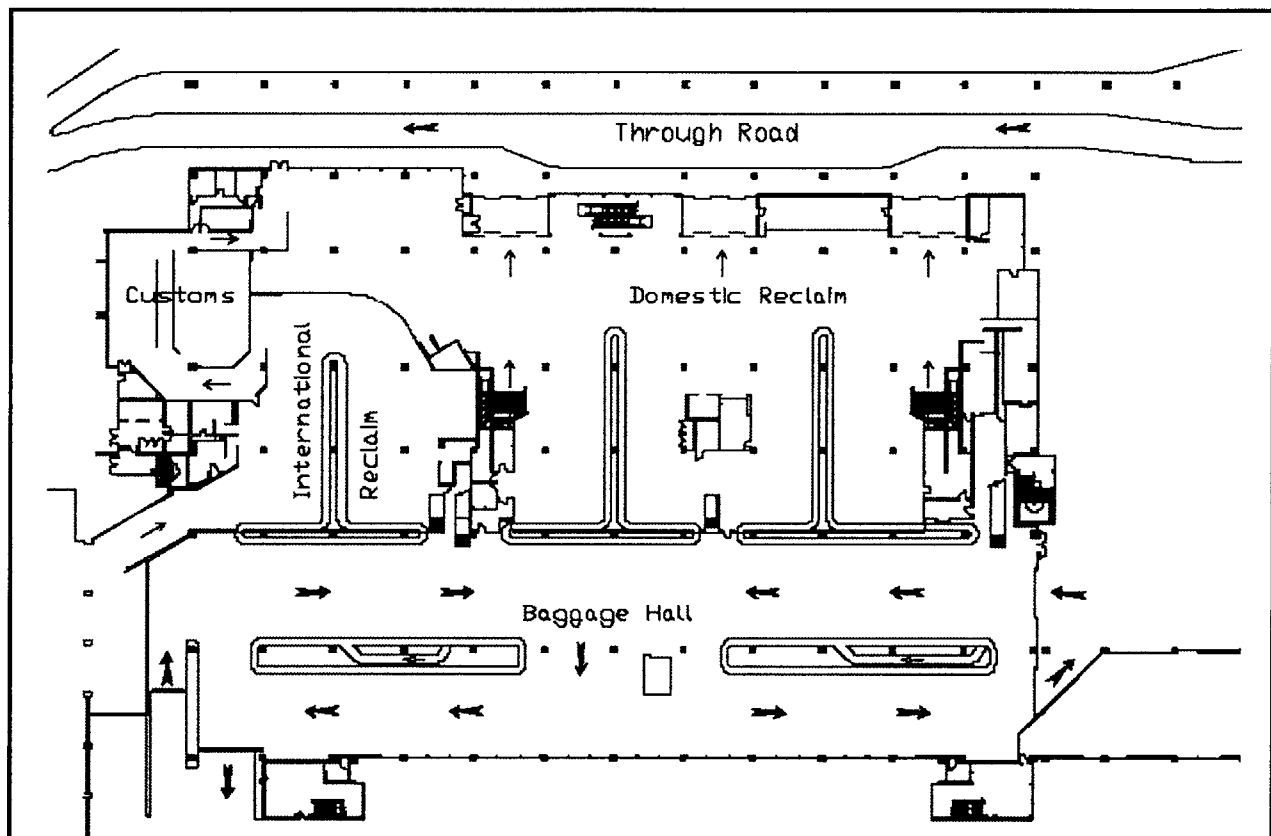


Figure A2.8. International/Domestic Swing Baggage Claim at Wellington, New Zealand

ASIA

Bangkok, Thailand - Second Bangkok International Airport

The articles below describe plans in the early 1990s for the planned passenger building development for the planned Second Bangkok International Airport. The plans have been evolving since then, but the basic concept to make some provision of swing gates is the same.

Source: Blow, C. Airport Terminals. Oxford: Butterworth-Heinemann, 1996, pp. 79-81.

51 gates, 28 of which will be dedicated international, 7 dedicated domestic, and 16 swing.

“The design sought to provide a unique type of flexibility and interchangeability between international and domestic traffic. This was achieved by parts of the building having 3 passenger levels to provide segregated routes for international and domestic arrivals and departures.”

Source: Revis, J. and King, C., (1995) “The Second Bangkok International Airport,” Transportation Research Circular, No. 445, pp. 13-20.

“Domestic and international passenger processing facilities will be integrated into both landside terminals. Aircraft gates and certain other facilities have been designed for use by either domestic or international passengers during respective peak hours, leading to economical use of terminal gate space.”

Kuala Lumpur, Malaysia

Contact Pier, 1998

Source: KL International Airport – Engineering Design for the Terminal Complex , Planning Report, Part IIB. KLIA Terminal Complex Design Consortium, Anglo Japanese Airport Consortium Sdn Bhd (1993)

“The second type of area is located along the length of the pier. These areas contain departure lounges, circulation spaces and gate hold lounges. In order to increase the flexibility and improve efficiency, it is proposed that the Contact Pier will handle Singapore, Domestic and other International flights at certain times of the day. This is achieved by extending the Singapore level to the extremes of the CP and introducing the use of swing gates at the domestic level below to segregate international and domestic departing and arriving passengers through the utilisation of dual use boarding lounges.

Singapore / International gate lounges at the domestic level are linked visually with circulation areas above via void spaces which will contain the main roof structure. Screening will be used to prevent direct contact between these levels for security reasons.”

Osaka/Kansai

Source: “Breaking the Capacity Stranglehold: Japan’s Airports,” (1991) Jane’s Airport Review, April/May, pp. 23-26.

“The terminal concept...features a four-storey terminal within which the two upper floors will be dedicated to international departures, a middle floor for domestic arrivals and departures, and a lower level for international arrivals. The terminal will have 41 gates (30 international and 11 domestic, with six of the domestic gates adaptable for international operations). Because of its mix of international and domestic traffic within the same terminal, the opening of Kansai could well have a significant effect on overall traffic patterns within Japan, possibly even surpassing Narita as the country’s primary gateway. Narita handles only a few domestic flights and most passengers transferring to domestic services have to travel by bus to Tokyo/Haneda, 80 km away, with a minimum connection time of 3.5 hours. Narita could therefore find itself limited to originating and destination traffic with Kansai handling most of the domestic/international connection traffic.”

Source: Buchanan, P. (1994) “Kansai International Airport: Circulation,” The Architectural Review, Nov., Vol. CXCVI, No. 1173, pp. 70-73.

“Because the proportion of domestic to international flights varies throughout the day, considerable flexibility has been provided in the allocation of gates. A number of them, immediately to either side of the domestic lounge in front of the terminal, can be switched to serve either sort of destination by using a ‘swing gate’ system devised by Aeroports de Paris and refined by the Building Workshop. When these gates are being used for domestic flights, international passengers proceed along a walkway parallel to that for those arriving, before dropping to the floor of the boarding wing.”

Tokoname, Japan: planned Central Japan International Airport

Source: Muraoka, K. (May 2, 2000) "Clear for Takeoff: A New Hub Airport for Central Japan." http://www.pref.aichi.jp/aia/voice/no11/11_clear_for_takeoff.html

"Because this large-scale project is being approached as a private-sector venture, emphasis will be placed on profitability. For example, the airport will have 'swing gates' whose usage can be switched between domestic and international flights. And the terminal building will be designed to facilitate expansion in step with the future growth in demand for aviation services."

Source: Central Japan International Airport Co., Ltd. (May 3, 2000) "Passenger Terminal Area Basic Plan" <http://www.cjiac.co.jp/eng/ejigyoku/PTB.html>

"User-Friendly, Simple and Compact Passenger Terminal

2. Universal Design: Minimum vertical movement for passengers created by one departures level and one arrivals level. Smooth passengers movement between MAT and their flights via ramps without traversing any vertical steps....

3. Compact & Efficient: Easy transfer between international and domestic flights realized by adjoining international and domestic facilities in a single terminal building. Creative layout of amenity spaces and greenery....

5. High Expansion Flexibility: Easy-to-expand capability made possible by modular design. Flexible planning concept to accommodate unforeseen future demand."

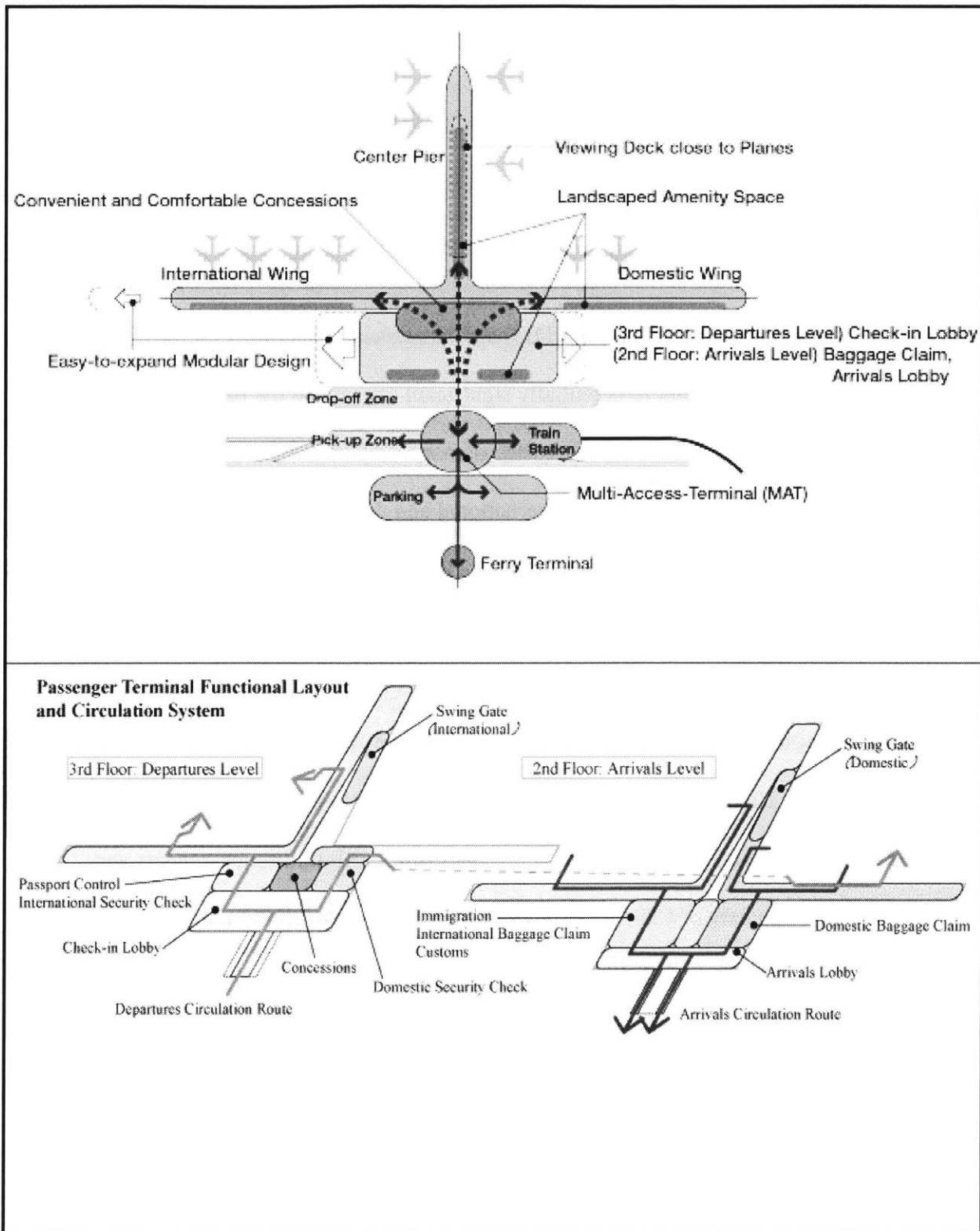


Figure A2.9. Passenger building at planned new airport, Tokoname, Japan

AFRICA

Cairo, Egypt

TB2 and TB3

Source: Cardinal Engineering Corporation (North Carolina), affiliated with ECGSA (Egypt) (Jan 31, 2000) "Cairo International Airport Terminal Area No. 3"
<http://www.cardinal-engineering.com/WebHtml/CIA.htm>

"Construction of a new terminal area No. 3 (TB3) and its associated facilities for the Cairo International Airport that can adapt to potentially significant changes in the future. The concept is developed in a modular form since the forecasted demand may increase. TB3 is physically connected to TB2 and both serve the mix of international and domestic passenger traffic through swing gates (maximum use of facilities by dual use). TB3 is designed to be used concurrently with TB2, while maintaining passenger services at TB2. This integration enhances the capacity of TB2. The combined annual capacity of TB2 and TB3 is fourteen (14) million passengers. The project increases the annual capacity of Cairo International Airport to twenty (20) million passengers by the year 2010 based on traffic forecasts. Upon implementation of the extension for TB3, the combined capacity of TB2 and TB3 reaches thirty (30) million passengers and ultimately the annual capacity of Cairo International Airport increases to more than fifty (50) million passengers.... TB3 is provided with two (2) fingers with extendible capacity and fifteen (15) swing gates facilities serving international and domestic flights. The gates are provided with fifteen (15) contact stands that can be increased to twenty (20) for small aircrafts and forty-seven (47) remote stands."

Mombasa, Kenya

Swing gates were part of the new terminal development at Mombasa MOI International Airport, 1995.

EUROPE

Birmingham, U.K.

Euro-hub, 1991

Source: Woolley, D. (1990) "Birmingham's Euro-Hub Forges Ahead," Airport Forum, Feb., pp. 30-32.

"Extreme flexibility is the order of the day; any gate may serve as an international or a domestic gate; and the internal divisions can be reconfigured relatively easily. In this way, the company hopes to cope with whatever requirements emerge after 1992....A sophisticated door control system, operated from a central position, will assist in the control of passenger flows....some other carriers, including Swissair and Lufthansa, have reacted to the hub development by adjusting their Birmingham schedules to allow better connections. The proportion of transfers is likely to grow to about 35% during the next four to five years."

Source: Paylor, A. (1991) "Eurohub: New Hubbing Concept Takes an Early Lead," Jane's Airport Review, Vol. 3, No. 6, p. 23.

"The first dedicated hub of its kind to be built in Europe, Eurohub utilizes a complex system of passenger flow control, which has never before been used in an airport terminal application, to ensure separation between international and domestic passengers. As a result, an aircraft can arrive at a gate as an international arrival and depart from that same gate as a domestic flight.

The centre of the building houses the passenger handling areas, quartered into international arrivals and domestic departures on one level, with international departures and domestic arrivals on the other. A unique centrally controlled passenger routing system known as 'door valving' is the key. Combinations of locked and open doorways route passengers around

the terminal to, from, or between flights, creating the effect of having twice as many gates as there are in reality. With this system, the target minimum transfer time is just 30 minutes.

The terminal has 10 gates, all served by airbridges, and incorporates a business centre and valet parking. The aim is to provide a fast hub point connecting all the UK regional airports with Europe.”

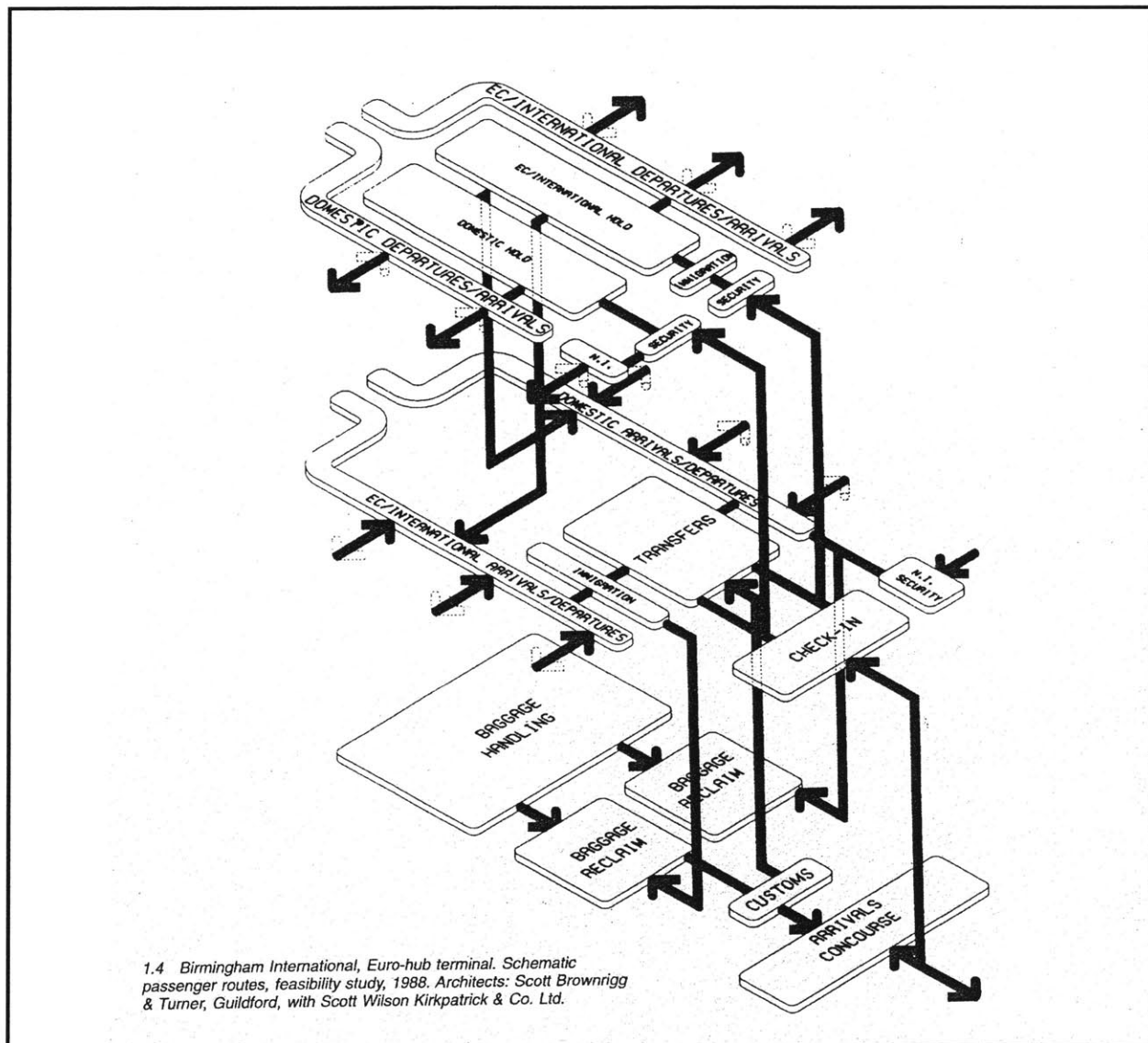


Figure A2.10. Birmingham Eurohub Flow Diagram
(Reproduced from: Blow, C. Airport Terminals. Oxford: Butterworth Heinemann (1996)

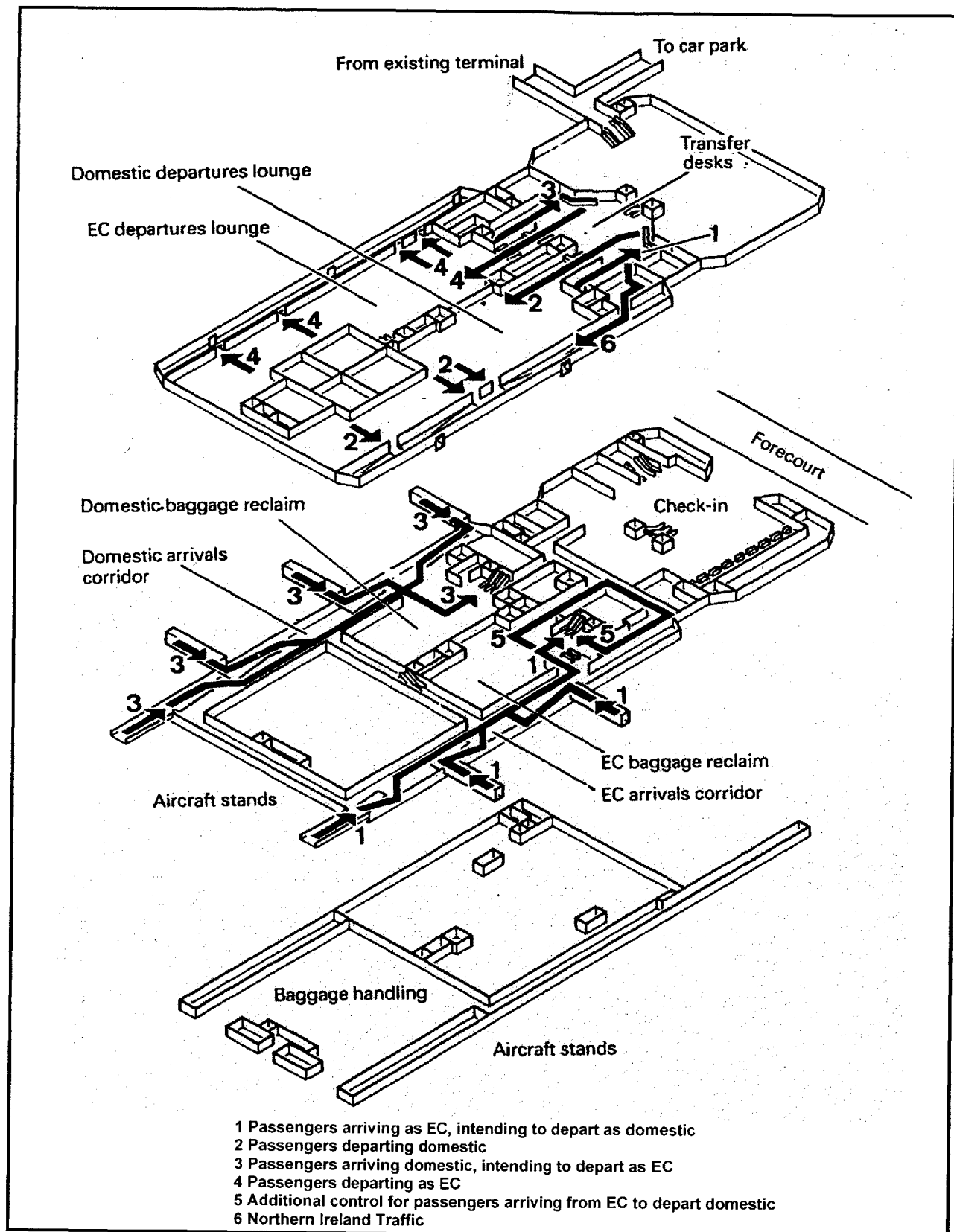


Figure A2.11. Birmingham Eurohub Transfer Flow Diagram
 (Reproduced from: Blow, C. Airport Terminals. Oxford: Butterworth Heinemann (1996))

Appendix III: Methodology for Choosing Optimal Flexibility to Normal Variability

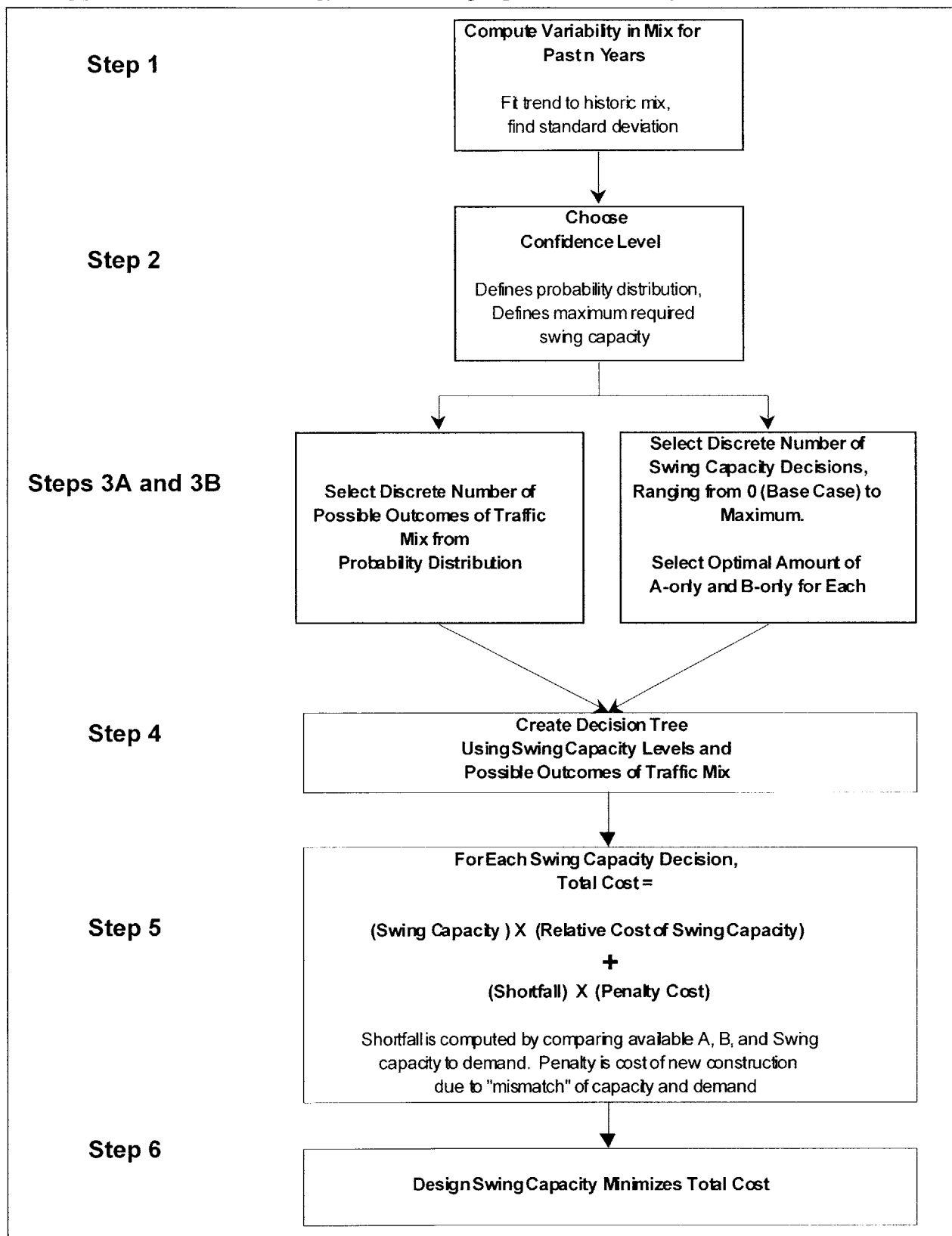


Figure A3.1. Methodology for Choosing Optimal Flexibility to Normal Variability

Figure A3.1 diagrams the methodology for estimating the optimal flexibility to cover normal variability in annual traffic mix, which was explained in Section 4.4.1. The following discussion expands on that in Chapter 4. While the discussion is based on gate capacity and demand, the approach could be applied to any unit of capacity.

Figure A3.2 shows conceptually the probability distribution around the forecast mix within which the actual future mix will fall. This is estimated from the historic volatility in the traffic mix as it is reasonable to assume that regular annual variations associated with cycles in the economy will continue to exist in the future at least as much as it has in the past.

Assuming the population is normal, the sample is small, and the population variance is unknown, the t distribution is used. This provides all of the inputs needed for the decision analysis: the possible events (i.e., actual future traffic mix); the probabilities of each event; combinations of the number of swing, A-only, and B-only gates; and the gate shortfall for each combination for each event, which gives the “penalty ” that will be applied when there is not enough of the right kind of gate for the actual traffic mix.

First, compute the traffic mix (i.e., percent international) for past n years. Fit a linear trend to the traffic mix and compute the sample standard deviation of the mix of traffic as

$$s = \sqrt{\frac{\sum_{i=1}^n (\text{actual}_i - \text{trend}_i)^2}{n - 1}} \quad (3)$$

Instead of planning for a particular year, planning is assumed to be done for a particular number of annual passengers.

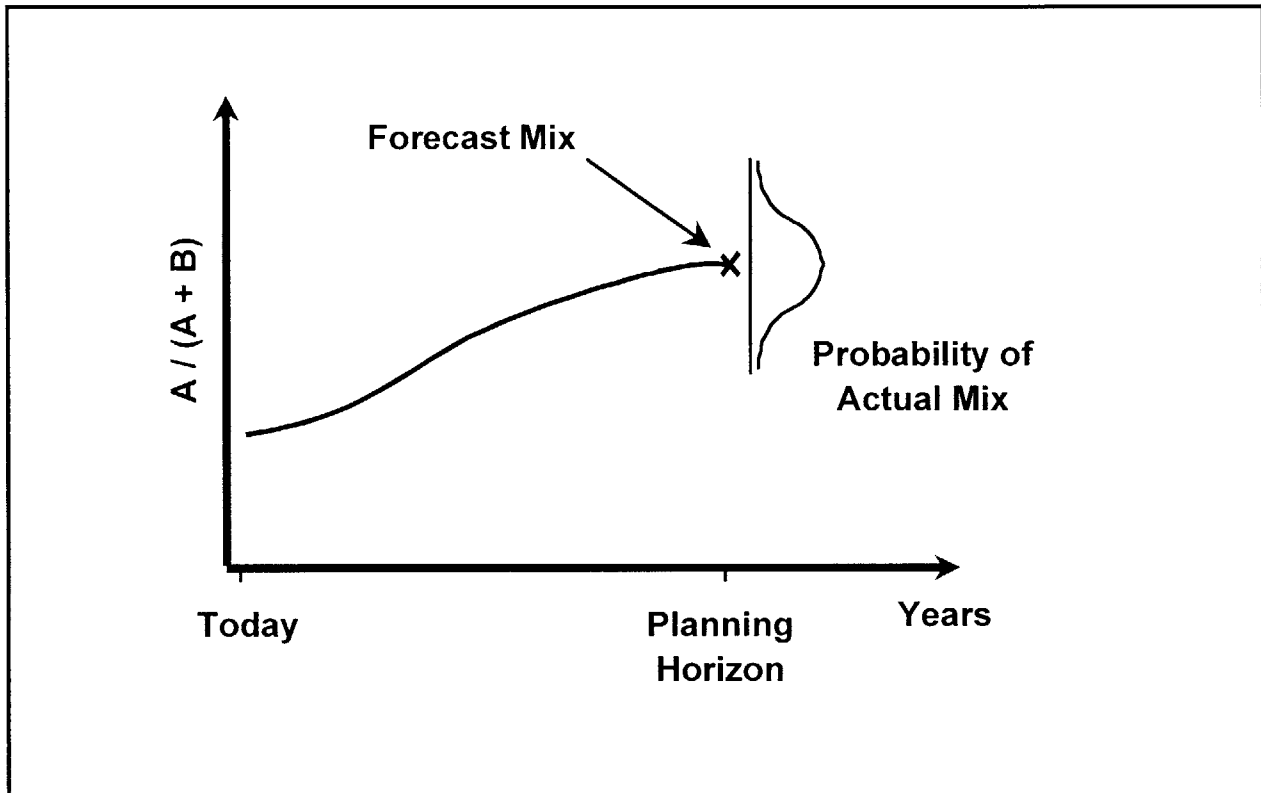


Figure A3.2. Annual Variability Creates Probability of Actual Mix around Forecast Mix

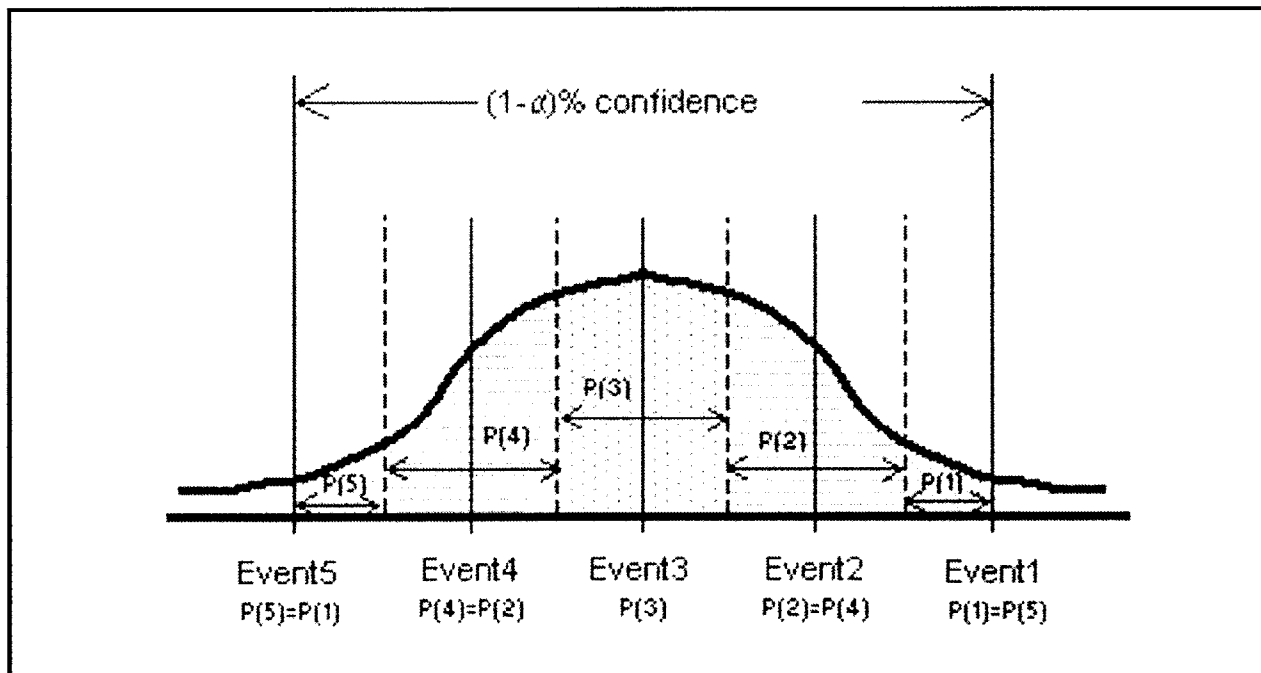


Figure A3.3. Probabilities Obtained from Past Variability, Here for 5 Discrete Events

First, we need to define some variables:

Let P = MAP at planning horizon. Assume each gate can handle C MAP.

Then, $G = \text{Minimum \# Gates Required} = P / C$.

M_F = Forecast Mix of traffic (expressed as “%A”)

M_A = Actual Future Mix of traffic (expressed as “%A”)

The range in which actual mix is likely to fall is: $M_F \pm Xs$. This is the confidence interval, within which we are $(1 - \alpha)\%$ confident that the actual value will fall.

$$\text{Prob}[M_F - Xs < M_A < M_F + Xs] = (1 - \alpha)\%$$

The size of the range around the forecast in which there is $(1 - \alpha)\%$ probability that the actual mix will fall is $2Xs$. The *maximum* number of swing gates to cover annual variability is equal to $2XsG$. The actual recommended number of swing gates will come from the decision analysis.

Solve for X given the desired confidence interval.

$$X = \frac{t_{\alpha/2}(n-1)}{\sqrt{n}} \quad (4)$$

The decision analysis includes five possible “events” for the future traffic mix, and five possible numbers of swing gates.

Number of Swing Gates to Evaluate (numbers rounded to integers):

Decision 1:	$2XsG$	Swing Gates
Decision 2:	$1.5XsG$	Swing Gates
Decision 3:	XsG	Swing Gates
Decision 4:	$0.5XsG$	Swing Gates

Decision 5: 0 Swing Gates

Possible Events:

Event 1: $M_F + X_s$

Event 2: $M_F + 0.5X_s$

Event 3: M_F

Event 4: $M_F - 0.5X_s$

Event 5: $M_F - X_s$

The probabilities of these events (i.e., actual deviation around any forecast) are all calculated using the t distribution and the confidence interval, shown in Figure A3.3.

For each of the five “number of swing gates” decisions, several combinations of A-only and B-only gates are feasible. The sum of swing, international, and domestic gates is constrained to equal G. Any shortfall that exists in the case of each event (actual mix) being realized is treated as a penalty. Assume the construction cost of a gate is X (regardless of type) and the average additional cost of adding swing capability to a gate is Y. The relative cost of swing capacity is Y/X.

Let:

S_S = Swing gate supply (can serve A or B)

A_D = Actual future demand for A gates = $M_A G$

B_D = Actual future demand for B gates = $(1 - M_A)G$

For each decision on S_S ,

A_S = Decision to supply number of A-only gates

B_S = Decision to supply number of B-only gates

S_A = Swing Gates reallocated to A

S_B = Swing Gates reallocated to B

Note that the decision tree selects the minimum cost initial decision on A and B for each decision on S_S , considering that actual future demand is unknown but defined by the standard deviation and confidence interval.

Let:

A_N = Gate Shortfall for A (Needed future gate construction)

B_N = Gate Shortfall for B (Needed future gate construction)

The algorithm on the next page shows how the gate shortfall is determined. Essentially, it checks whether demand for A or B is greater than their supply. If so, it reallocates as many swing gates as needed from the available pool of swing gates to cover demand. Any demand not covered once all of the available swing gates have been reallocated is the shortfall. Any shortfall is treated as a penalty, because new gates would be needed to cover the demand. The magnitude of the penalty is the construction cost per gate.

The total cost of any outcome is thus the sum of the gate shortfall times the penalty per gate plus the cost of providing the swing capacity times the amount of swing capacity provided. The swing capacity decision which minimizes the expected value of total costs provides the recommended amount of multifunctionality.

Figure A3.4 shows the optimal provision of swing capacity to cover normal variability, as defined by the decision which results in the minimum total cost of swing capacity and gate shortfall penalty.

The total shortfall for each decision and actual mix is calculated as follows:

If $A_S < A_D$,

If $S_S > (A_D - A_S)$,

$$S_A = A_D - A_S,$$

$$A_N = 0;$$

Otherwise,

$$S_A = S_S,$$

$$A_N = A_D - A_S - S_A;$$

Otherwise,

$$S_A = 0,$$

$$A_N = 0;$$

If $B_S < B_D$,

If $(S_S - S_A) > (B_D - B_S)$,

$$S_B = B_D - B_S,$$

$$B_N = 0;$$

Otherwise,

$$S_B = S_S - S_A,$$

$$B_N = B_D - B_S - S_B;$$

Otherwise,

$$S_B = 0, B_N = 0;$$

$$\text{Total Shortfall} = A_N + B_N$$

$$\text{Expected Value of Cost} = (S_S * Y) + (A_N + B_N) * X$$

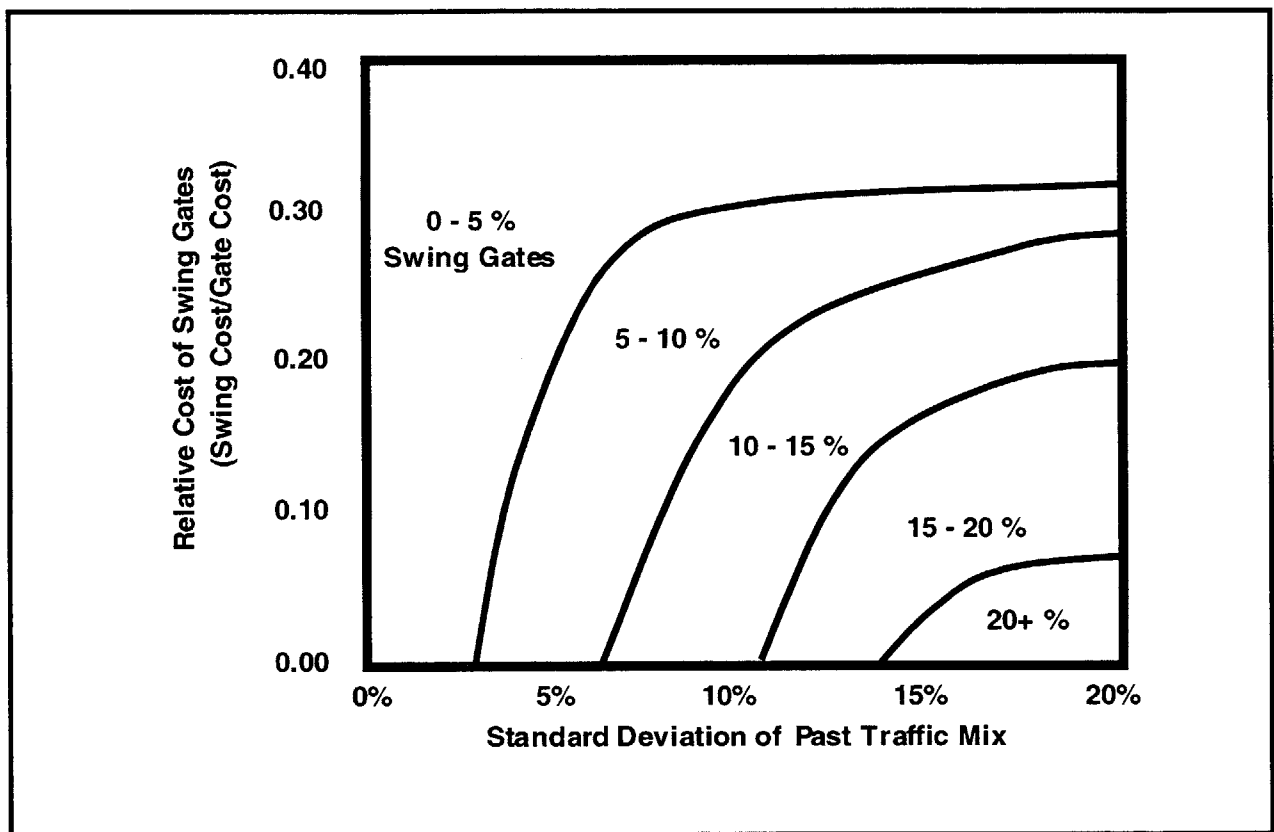


Figure A3.4. Optimal Number of Swing Gates as a Percentage of Total Gates

Appendix IV: Methodology for Choosing Optimal Flexibility to Major Shift

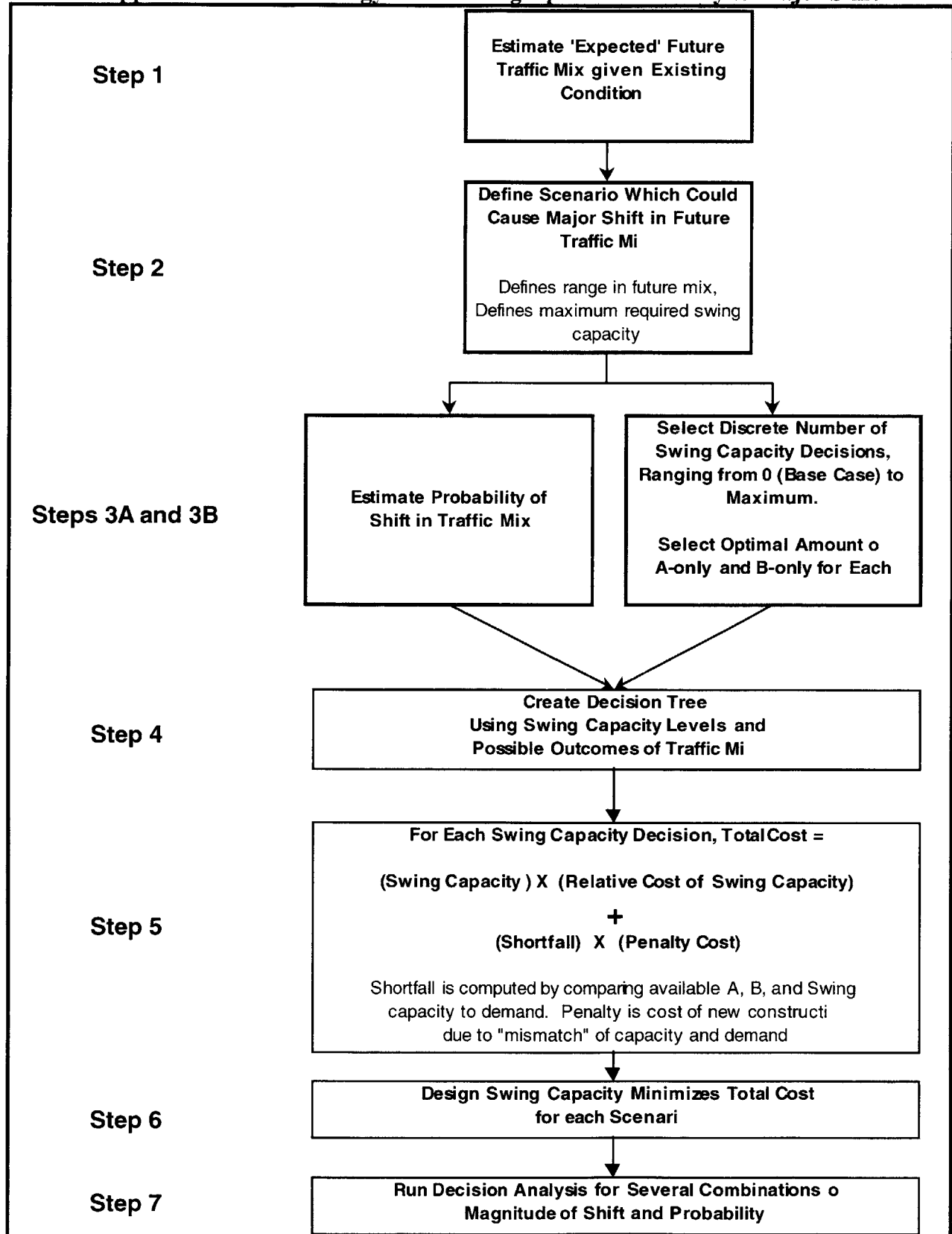


Figure A4.1. Methodology for Choosing Optimal Flexibility to Major Shift

Figure A4.1 diagrams the methodology for estimating the optimal flexibility to cover a major shift in annual traffic mix, which was explained in Section 4.4.2. The following discussion expands on that in Chapter 4. While the discussion is based on gate capacity and demand, the approach could be applied to any unit of capacity.

Assume two users, A and B. Mix is defined as %A.

Let: P = MAP at planning horizon. Assume each gate can handle C MAP.

Then, $G = \text{Minimum \# Gates Required} = P / C$.

M_H = High Forecast Mix of traffic (expressed as “%A”)

M_L = Low Forecast Mix of traffic (expressed as “%A”)

L_H = Likelihood (probability) of M_H

L_L = Likelihood (probability) of $M_L = 1 - L_H$

$R = \text{Range on Future Mix} = M_H - M_L$

Range on Future Gate Requirement for A = $R * G$

Range on Future Gate Requirement for B = $(1 - R) * G$

M_A = Actual Mix at Planning Horizon (expressed as “%A”)

A_D = Actual future demand for A gates = $M_A G$

B_D = Actual future demand for B gates = $(1 - M_A)G$

M_E = Expected mix (% A) = $(M_H * L_H) + (M_L * L_L)$

S_S = Swing gate supply (can serve A or B)

The decision tree is set up similar to that for the annual variability, except that arbitrarily only four “number of swing gates” decisions are included instead of five. The more decisions included, the more “fine-grained” the analysis.

Number of Swing Gates to Evaluate, S_S

Decision 1:	$R * G$	Swing Gates
Decision 2:	$(2/3) * (R * G)$	Swing Gates
Decision 3:	$(1/3) * (R * G)$	Swing Gates
Decision 4:	0	Swing Gates

For each of the four “number of swing gates” decisions, several combinations of A-only and B-only gates are feasible. The minimum cost choice of A-only gates is a function of the expected value of A, defined by the range and the probability of each scenario. This centers the swing capacity around the expected value of the mix, minimizing the cost of the A and B decision for any S_S .

$$A_S = \text{Optimal A-only gates} = \min[\max(M_E G - S_S/2, M_L * G), \min(M_E G + S_S/2, M_H * G)]$$

$$B_S = \text{Optimal B-only gates} = G - A_S - S_S$$

$$S_A = \text{Swing Gates reallocated to A}$$

$$S_B = \text{Swing Gates reallocated to B}$$

Any shortfall that exists in the case of each event (actual mix) being realized is treated as a penalty. Assume the construction cost of a gate is X (regardless of type) and the average additional cost of adding swing capability to a gate is Y. The relative cost of swing capacity is Y/X . The recommended number of swing gates is chosen as that with the minimum expected value of total costs, including the cost of providing the swing gates.

Note that the decision tree only considers the minimum cost initial decision on A and B for each decision on S_S , considering that actual future demand is unknown but defined by the standard deviation and confidence interval.

Gate Shortfall for A (Needed future gate construction) = A_N

Gate Shortfall for A (Needed future gate construction) = B_N

Figures A4.2 and A4.3 show the optimal swing capacity and the expected value of cost savings for combinations of relative cost, shift size, and shift probability.

The total shortfall for each decision and actual mix is calculated as follows:

If $A_S < A_D$,

If $S_S > (A_D - A_S)$,

$$S_A = A_D - A_S,$$

$$A_N = 0;$$

Otherwise,

$$S_A = S_S.$$

$$A_N = A_D - A_S - S_A;$$

Otherwise,

$$S_A = 0,$$

$$A_N = 0;$$

If $B_S < B_D$,

If $(S_S - S_A) > (B_D - B_S)$,

$$S_B = B_D - B_S,$$

$$B_N = 0;$$

Otherwise,

$$S_B = S_S - S_A,$$

$$B_N = B_D - B_S - S_B;$$

Otherwise,

$$S_B = 0, B_N = 0;$$

$$\text{Total Shortfall} = A_N + B_N$$

$$\text{Expected Value of Cost} = (S_S * Y) + (A_N + B_N) * X$$

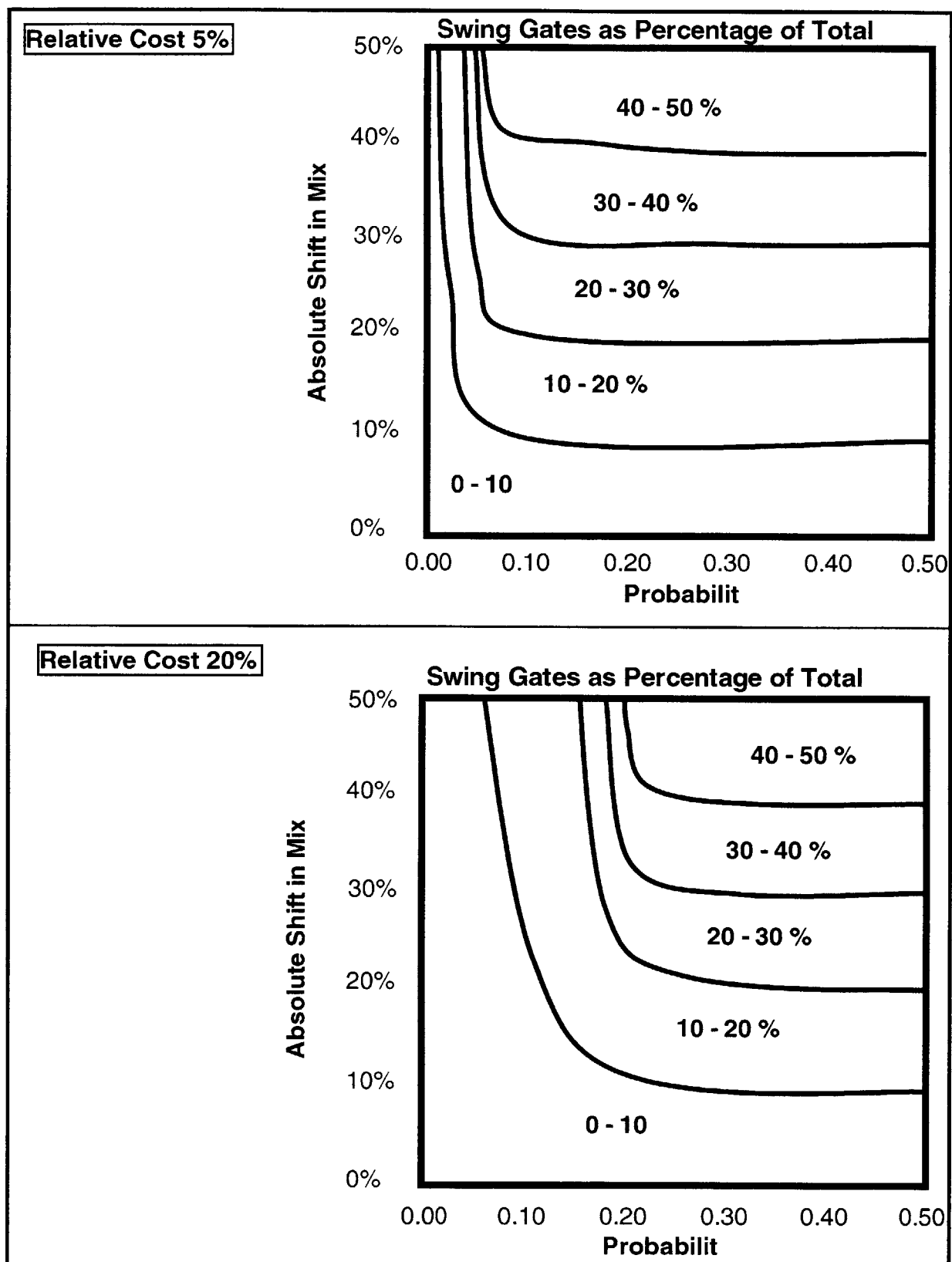


Figure A4.2. Number of Swing Gates as Percentage of Total Gates

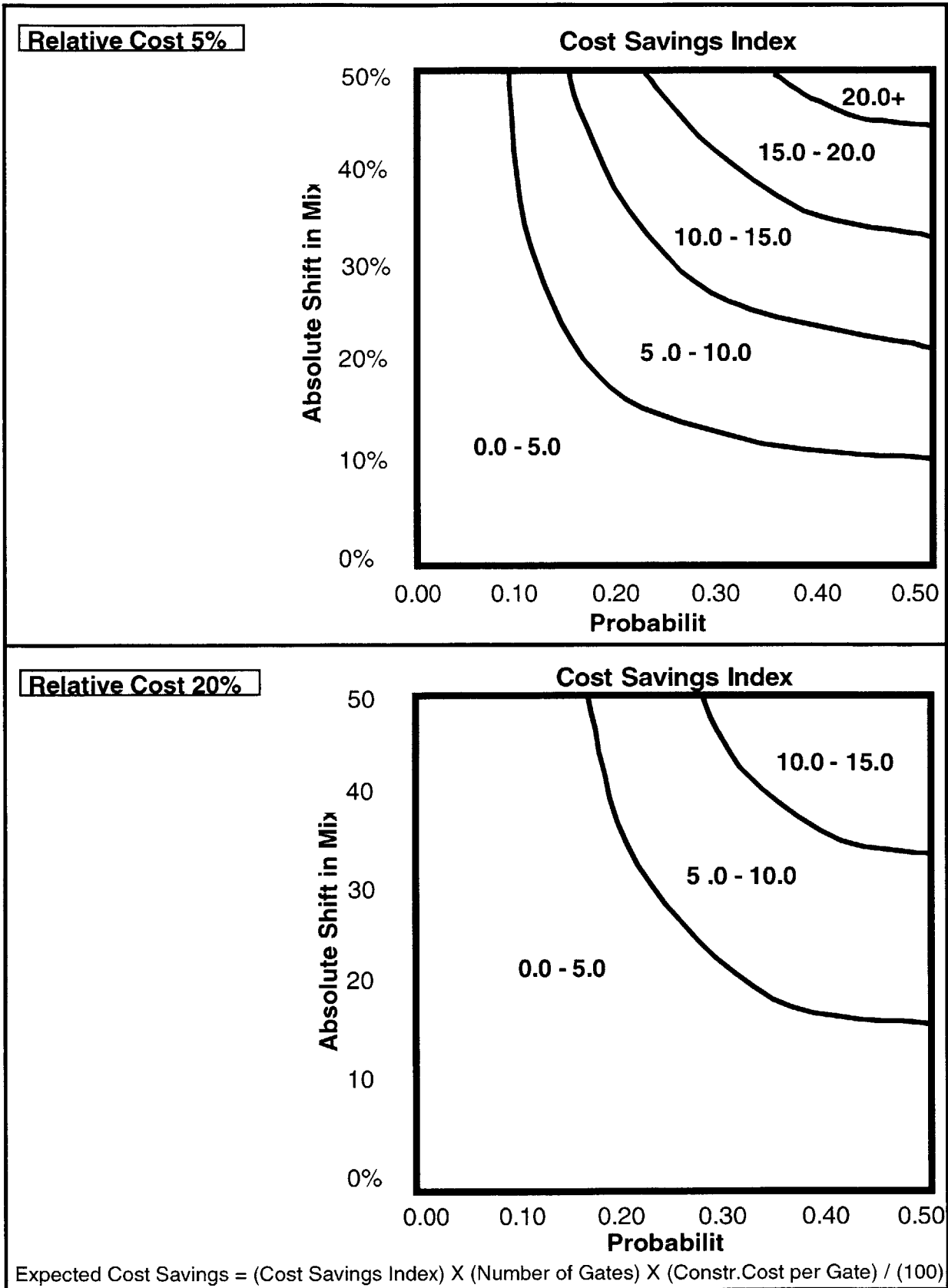


Figure A4.3. Expected Value of Cost Savings Normalized by Construction Cost per Gate

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