Workshop 5 Resource Paper

DESIGNING THE AIRPORT TERMINAL

Richard de Neufville, Center for Transportation Studies, Massachusetts Institute of Technology

The purpose of this paper is to provide the conceptual and analytical framework for determining the best alternatives for providing landside capacity at airports. The basic premise is that many current problems at airports are due to the unfortunate tendency of airport planners to impose a single design concept on the entire terminal area. Centralized terminals are easier for transferring passengers, gate-arrival terminals are better for short-haul commuters, transporter designs are more economical for peaks of traffic, and so on. To determine the best design, we must examine the variations in the traffic. Since the major differences among the alternative design concepts lie in their ability to handle transfers and to deal with peaks of traffic, we should concentrate on determining the percentage of transfers and the variations in the level of traffic. Based on this point of view, the paper summarizes the major distinctions in airport traffic in the United States and around the world. The paper next examines the major questions concerning the fundamental nature of the terminal facilities at an airport. Should the facilities be centralized in a single major complex or decentralized into separate terminals or gates as with the gate-arrival concept? Should transporters be used almost exclusively, partially, or not at all? To what extent should the facilities be shared by different airlines? For each question, we develop a simple analytic model to explore the principal issues and trade-offs and to indicate the general circumstances for which each of the major alternative design concepts is most appropriate. The results of these analyses generally indicate which combinations of design concepts should be chosen for airports with different mixes of traffic. The results also suggest an analytical procedure we can use to determine in detail the kind of design that is preferable for a particular site.

The airport terminal is the facility that provides the connection between the aircraft and the vehicles providing ground transport. This function is difficult to perform well: The different size and length of stay in the air and ground vehicles imply quite dissimilar amounts of space on the airside and landside of the terminal.

Typically, the stands for stationing the aircraft must occupy a much longer distance than the curb needed to provide for the loading and unloading of cars, buses, or other landside vehicles. How to balance these conflicting requirements, on opposite sides of the same set of facilities, is the essential question of terminal design. Until recently, this may not have been either a major or an important problem. But now things are different.

It used to be that terminals and related facilities for serving passengers accounted for only one-fourth or less of the cost of an airport. Until about 1965, most of the money had to be spent on making runways and taxiways longer, wider, and stronger to accommodate new generations of aircraft, especially the jets. This has changed. Aircraft manufacturers now recognize that airport designers find it nearly impossible to extend their runways farther or to obtain space near cities for airports with runways more than 2 miles (3 km) long. They have consequently designed the latest generation of aircraft—the 747 jumbo jets, the wide-bodied aircraft, and the airbuses—to operate on existing runways. But these new aircraft, serving hundreds of passengers at a time, require much larger terminal facilities than were needed before. Most of the money for airports, about three-fourths in the United States, will now be spent on terminals.

Individual terminals can also be extraordinarily expensive. The new American Airlines building in Boston will finally cost close to \$60 million or, including the value of the money invested, amortization, and maintenance, between \$5 and \$10 per passenger for the life of the structure. The new Pan American Terminal at New York (Kennedy) Airport reputedly cost more than \$140 million. An airline could go broke on terminals alone! We should, therefore, give careful consideration to the kind of terminal we build.

Unfortunately, airport planners have tended to think simplistically about the design of terminals. We have a long way to go before we will really know (rather than think we know) what solutions are best for particular problems, and we should recognize the limitations on our ability to define the best solutions. Meanwhile, we can hope to understand the forces that will shape this decision and to decide which concepts of design are most effective for different situations.

Terminals simultaneously facilitate a wide range of services for many users: arriving passengers, transfers, commuters without bags, travelers with many, visitors, and so on. There is no clear way to decide what is the cost of each service, let alone to determine how greater expense will improve a particular service by itself. On logical grounds, any kind of cost-effectiveness argument concerning different levels of service that might be obtained is likely to be dubious. We may thus never have clear guidelines for specifying in detail what levels of service a terminal ought to provide.

AVAILABLE CONCEPTS

Although the words used to describe types of terminal designs differ, they can be placed into 3 categories that represent fundamentally different views of how a terminal should function and whom it should serve:

1. Centralized with either finger piers or satellite subterminals,
2. Linear or gate arrival, and
3. Open apron or transporter.

[This typology is described in detail by Horonjeff (13, chapter 9) and is also analyzed in a joint report of the R. M. Parsons Company and the Air Transport Association of America (17). Since the ATA is the representative of the major U.S. airlines, its report reflects their particular interests. These cannot be presumed to be appropriate either for other countries or even for different elements of the community within the United States. Its report must be viewed accordingly, and its findings recognized as being quite controversial.]

Centralized Terminals

The characteristic feature of a centralized terminal is a common hall through which passengers must pass. The hall contains facilities for checking passengers and for handling their bags and also houses auxiliary services such as restaurants and stores. Passengers connect with the aircraft along corridors. In the finger pier design, the aircraft are located along the corridors. In the satellite design, the aircraft are placed at the end of the corridors. Examples are shown in Figure 1. Both designs provide essentially the same services, but satellites may allow somewhat more room for aircraft to maneuver, depending on their location. If the airport is large, the terminal area may include several centralized terminals. This occurs at Paris (Orly), London (Heathrow), Chicago (O'Hare), and San Francisco airports, for example.

Centralized terminals have many advantages. Airlines and airport operators like them because they promote intensive use of facilities and equipment and, thus, reduce the average costs of providing check-in and baggage-handling services. Passengers who have to transfer between flights also like centralized terminals because they are relatively compact. Conversely, the essential disadvantage of centralized terminals is that—at large airports—all passengers must go through a congested place and must travel a considerable distance between the vehicles that bring them to the airport and the aircraft. Although this distance may be covered on foot or via some form of moving sidewalk or automatic device like the skybus in use at Tampa or Seattle-Tacoma airports, it is an inconvenience, especially to commuters and others who may be in a great hurry.

Linear Terminals

The linear or gate-arrival concept was devised to eliminate long distances between the place of arrival and the aircraft. It allows a passenger to be driven right up to the gate to the aircraft. The airport is linear and has roads on one side and aircraft on the other (Figure 1). The gate-arrival design became fashionable in the late 1960s, possibly because few people had experienced, or thought about, the disadvantage of this approach.

A gate-arrival terminal naturally requires separate baggage-handling and check-in facilities at or near each aircraft position, significantly increasing the equipment and personnel needed to serve passengers. The maximum distance from one end to the other is much longer in a linear terminal than in a centralized terminal, especially if the former has aircraft on only one side of the building. The gate-arrival terminal can thus be quite unattractive both for transferring passengers and for returning travelers who wish to pick up cars they may have parked in front of some distant gate.

Open-Apron Terminal

The third concept substitutes vehicles for most of the terminal structures. These vehicles, generically called transporters, carry passengers between a central terminal and the aircraft parked on the apron. (These transporters are also called apron passenger vehicles in England and mobile lounges in North America. The term mobile lounge is really inappropriate since it is inefficient to use vehicles as lounges; they and their drivers should be in use, moving passengers to and from aircraft, as much as possible.) The prototype for this arrangement is Washington (Dulles) Airport, which serves essentially all passengers with transporters (a few walk to small aircraft through a miniscule finger pier).

The transporter reduces the amount of walking a passenger must do, but requires a large labor force of drivers and attendants and is potentially expensive. It is also potentially economical, since transporters can be parked and operated only when needed so that drivers can be hired for a fraction of the time, either for a specified shift or season. The transporter concept thus has a distinct economical advantage for handling peaks of traffic.

SIMPLISTIC CURRENT PRACTICE

Each of the available concepts of terminal design functions efficiently for some kinds of traffic: Centralized terminals are easier for transferring passengers; gate-arrival terminals are better for commuters; and open-gate terminals handle traffic peaks more economically. Any airport is likely to have a significant proportion of more than one of these types of traffic, and we should therefore expect that effective designs for terminals would combine the appropriate features of all the concepts.

Airport designers, however, typically develop master plans for terminals around only 1 of the 3 concepts and argue about which concept is best for all purposes. This debate is remarkably dogmatic. Recent controversies over new airports have demonstrated a singular unwillingness to compromise or to combine design concepts. The protracted arguments over the new Montreal (Mirabel) Airport are an example. The architects and planners in charge decided early on that a transporter design should be built and resisted compromise when airlines and others subsequently showed that this plan had several drawbacks. Finally, some sort of combination of concepts was agreed upon, but only after various airlines applied strenuous pressure. Elsewhere, for example at Frankfurt (Main), Dallas-Fort Worth, and Washington (Dulles) airports, the situation has been similar: Politically powerful institutions or persons have imposed their favorite design on the users.

This kind of fight is unnecessary, for a diversity of needs can best be served by a mixture of the elements that best serve each need. We should start with the premise that the best design for an airport terminal is likely to be some hybrid of a pure concept (Figure 2). A rational combination of elements, however, is difficult to achieve for several reasons. In the United States, architects usually design airport terminals, and they naturally think of form and external beauty. In France and Germany, airport designers are engineers, who tend to like mathematically clever and geometric designs. The designs for practically all new airport terminals, therefore, are remarkable for their symmetry, elegance, and even beauty.

The users and operators of an airport terminal want it to function smoothly and efficently. They want a variety of significantly different kinds of services, such as easy access to all aircraft and easy transfers. The diversity and complexity of their desires inherently conflict with aesthetic preferences of the designers for simplicity of concept and form; this conflict is now dominated by the designers.

Better terminals for the airlines and the travelers can be designed if we concentrate on the functions to be served, not on the form. We may need to restrain the architectural considerations to the extent they disordinately dominate the design process. [The current dominance of architects in the design of terminals is suggested by their responsibility for the available textbook treatments of the subject (7, 13, 19).] Instead, we need to emphasize pragmatic considerations in the selection of the concept for the terminal. These are largely missing. Our problem will be to determine what combination of concepts provides the most suitable design for the particular mix of traffic at any airport. To do this, we need to understand the different kinds of traffic using airport terminals and their implications for the choice of design.

NATURE OF TRAFFIC

To understand a problem, we have to measure its important characteristics. Here is where we often fail because we assume that the kind of statistics that are available are suitable for our purposes. This is not so. The appropriate description of a situation depends on our point of view. A professor looking at a classroom will count the number of seats, for example, while the junkman will estimate the pounds of scrap.

Various organizations collect extensive data about air travelers: Customs officials count the number of international passengers; air traffic controllers count the number of aircraft movements; airline companies count the number of passengers and their destinations, and so on. These groups do not gather statistics for the benefit of terminal designers, however. They collect the data for their own administrative purposes

Figure 1. Examples of use of pure concepts for terminal design.

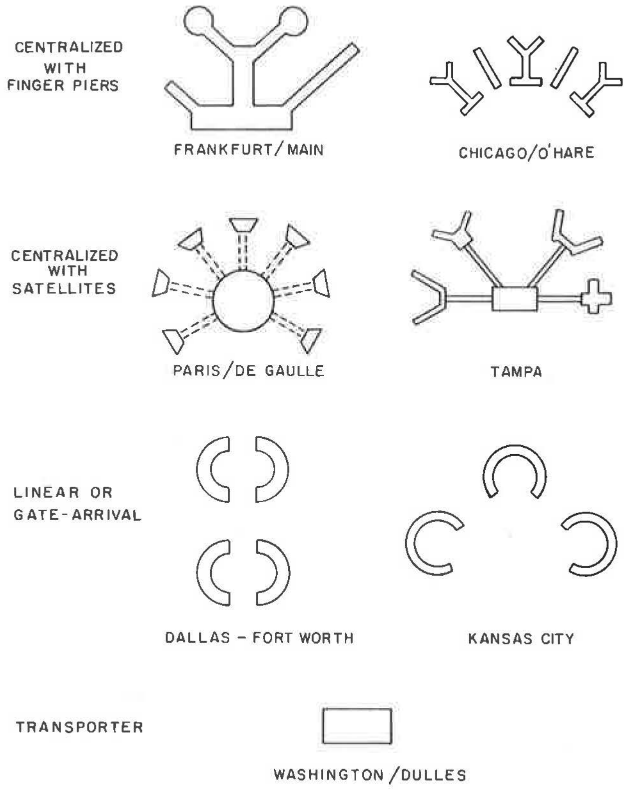
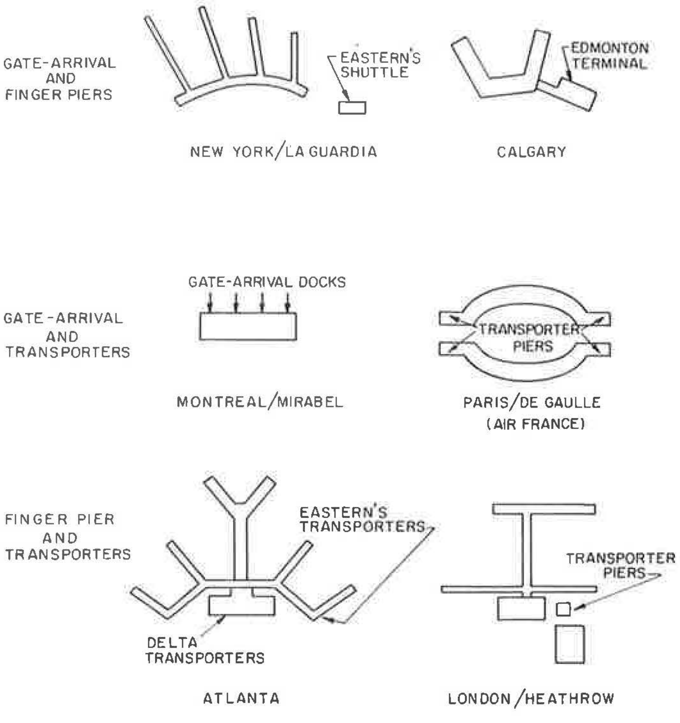


Figure 2. Examples of use of hybrid concepts for terminal design.



and may be quite willing to accept peculiarities that are inappropriate for designers. Air traffic controllers, for example, count training flights together with actual airline arrivals. This practice makes sense in terms of keeping track of their work load, but is confusing to the designer interested in the number of aircraft that need to be accommodated at the terminal. (Data are also often subject to systematic biases. At smaller airports it is not uncommon, for instance, for the statistics on aircraft operations to be distorted upward because flight controllers get higher pay when their work load increases.) In designing terminals, we must therefore be careful in interpreting data about airport traffic.

Current practice focuses on the problem of identifying the daily and hourly volumes of future passengers and aircraft that the facilities should accommodate. The object is to obtain reasonable approximations to the peak flows so that each of the elements of the terminal can be sized correctly. The process develops traffic estimates, for example, of the peak hour of the average day of the peak month. These figures are useful for calculating the capacity of the system for handling bags, the width of the corridors, and other dimensions. But they provide no clue about what kind of facilities might prove most effective or economical, and that is the more fundamental question. Before sizing a facility we need to know what it looks like. Unfortunately, current practice does not develop the kind of information needed to address this issue.

What kind of data are most useful for choosing the right mix of concepts for a terminal? Which aspects of the traffic have the most important consequences for its performance? The answer is that we should focus on the aspects that will help us decide what kinds of terminals we want. Since the major functional differences between the alternative design concepts lie in their ability to handle transfers and to deal with peaks of traffic, we should concentrate on examining the variations in the level of traffic and the percentage of transfers. Conversely, the conventional categories of traffic used in terminal design (for example, the number of passengers on business or pleasure or on domestic or international flights) do not tell us very much about what combination of concepts are right to use for a terminal. At best, they provide an indirect guide. Data on international traffic might be most helpful for our purposes in Boston since they would define highly peaked daily and seasonal traffic across the Atlantic, but they would not give us much indication of what terminals might be best for London, where much of the international traffic is steady, year-round business travel within Europe.

The relative importance of transfers at an airport is a significant factor for helping decide among concepts for terminal design. It is also most difficult to determine. First of all, data on the number of passengers transferring between flights are not regularly collected by any agency. These statistics must be pieced together indirectly or measured by sample survey; some typical results are given below for domestic, interstate travelers transferring between flights in 1971.

Airport	Percent
Atlanta	72
Dallas	53
Chicago	49
Philadelphia	39
Denver	36
New Orleans	32
Kansas City	32
San Francisco	31
Los Angeles	30
Miami	29
Minneapolis-St. Paul	27
Detroit	19
Boston	15
New York	15

[Although the number of transferring passengers has important implications for the design of airport terminals and for the demand for airport access and should, therefore, be readily available to airport planners, this figure is often unknown. This is because the number of transferring passengers, as opposed to the number of passengers, is usually not generated in the ordinary course of events as a by-product of some other necessary activity, such as financial accounting. The number of transfers generally has to be deduced from the results of special surveys. The numbers above were obtained by comparing the total number of passengers boarding aircraft in the United States (23) with the number of originating passengers as estimated by a sample survey (22). The results are only accurate for the domestic, interstate operations under the supervision of the Civil Aeronautics Board. The estimates for San Francisco, Los Angeles, and Dallas are thus tentative because many passengers use airlines that fly only within the states of California and Texas. The point is that considerable subtlety and care have to be used to obtain good estimates of transfers.]

The percentage of transfers varies greatly. Some airports, such as Chicago (O'Hare), Atlanta, and Dallas-Fort Worth function as major interchanges. It, therefore, stands to reason that their terminals should emphasize convenient accessibility among all sections. (From this perspective, the gate-arrival terminals built at the new Dallas-Fort Worth Airport would seem to be just the wrong kind of solution for this location, since they impede transfers. It would be interesting, but not too surprising, to find that Dallas-Fort Worth had lost its importance as a transfer point after a few years).

The importance of transfers is also difficult to determine because the persons going from one flight to another represent only a fraction of the people effectively transferring through the terminal. This is especially true at decentralized terminals. Indeed, many passengers may park their cars near one section of the terminal, from which they depart, and then return, on a different airline or from a different city, to another section. To get back to their cars, they must go through the terminal area just as if they were transferring. We may call these people cryptotransfers. Their problems may actually be worse than those of the passengers transferring between flights: They have to handle their own bags, while a passenger connecting between flights can rely on the airlines to do this.

These additional transfers may be important at some airports. Although no direct measure exists for these cryptotransfers, circumstantial evidence suggests that they can be numerous. After the opening of the gate-arrival terminal at Kansas City, for example, it was noticed that many passengers avoided the parking lots near the gates and used the more distant—but centrally located—spaces. This effect was certainly reinforced by the fact that the central parking was cheaper. Nonetheless, the same effect occurs at Boston and Dallas-Fort Worth. Cryptotransfers may account for as much as 10 percent of the traffic.

The variability of the flows of traffic is the other major determinant of the choice of terminal concepts. When the traffic fluctuates widely, we can expect that many of the facilities needed to provide services during peak periods will be idle most of the time. Under these circumstances, it becomes economical to turn off the cost of the facilities when they are not required. This cannot be done with buildings, where most of the cost is fixed in the structure. But it can be done with transporters, for which most of the cost lies in the operating expenses of the drivers, fuel, and maintenance. Transporters can be parked when not needed, and drivers can be hired only for a specified shift or season. The transporter concept is most economical for handling peaks of traffic.

Figure 3 shows the number of months for which the passenger traffic exceeds any given percentage of the month with the least traffic. The steeper the slope is, the greater the peaks in the traffic. (These figures can be derived from annual reports from agencies such as the British Airports Authority, Port Authority of New York and New Jersey, and Aeroport de Paris, and Flughafen Zurich. All airports can be expected to maintain records of this sort even if, as for Los Angeles, they are not published.) Typically, smaller airports serving vacation resorts, like Grand Junction, Colorado, or Ibiza, Spain, have the greatest seasonal variations. Larger tourist

attractions, like Mexico City or Miami, may have substantial peaks around the weekends, when holidays usually begin and end.

For New York, the strongest peaks occur in the international traffic. For a brief 2 months (the July and August vacation period), about half again as many passengers require service as at any other time during the year. Similar variations occur around London. But in London the major international airport, Heathrow, has the most even pattern of traffic. This emphasizes that the conventional categories of traffic do not really give us much information about the nature of the traffic that we can use in choosing the right concept for a terminal. What happens is that the holiday traffic, which gets routed through New York (Kennedy) Airport, goes through London (Gatwick) or Luton Airport via charters (or "nonscheduled" carriers as they are often called in the United States). The wide variation in holiday traffic is emphasized by Zurich figures, which are published separately, for scheduled airline service and charters (Figure 4).

Daily fluctuations can also be important. Some airports, such as Cleveland (Hopkins), are steadily busy through most of the day, while others, like Miami, evidence sharp peaks, as shown by Figure 5 (24). Some airports are also sensitive to particular travel patterns or to time zones. New York (Kennedy) Airport, for example, is particularly busy from 2 p.m., when the morning flights arrive from Europe, until 9 p.m., when these aircraft return. At other times the airport is virtually deserted. The pattern of international traffic through Montreal has a similar peak, and this provides a strong justification for the use of transporters at the new Montreal (Mirabel) Airport. (Conversely, such peaks argue against the trend to construct large terminals dedicated to international traffic at most North American cities. This, however, runs counter to most civic pride.)

Lack of punctuality of the arrivals of aircraft is another factor that influences the use of facilities and, thus, the desirability of transporters. We know that a large proportion of the flights will routinely fail to arrive on time, through any of a variety of meteorological, mechanical, and other problems. We consequently have to have equipment and personnel available for serving the aircraft much longer than is needed to perform the operations. The resulting relatively low levels of use of fixed facilities favor the use of transporters.

Arrivals are not particularly punctual. If being on-time is defined as operating within 15 minutes of schedule, which is the generous definition used by the United States airlines, then more than one-third of all flights are not on-time (Figure 6). To a certain extent, punctuality depends on the climate and deteriorates during the winter, when bad weather causes delays, rerouting, and cancellations. But it is also a matter of airline policy. Some airlines will deliberately hold back flights so that connections can be conveniently made from other flights. This is especially true of Delta, for example, which consistently has a lower percentage of its flights on time. In detail, the arrivals and departures of aircraft typically deviate considerably from their schedules. As shown in Figure 7 (11), flights are easily 20 minutes later on the average, and arrivals spread out over more time than departures. [Data on the punctuality of U.S. airlines are reported by the Aviation Week and Space Technology Magazine. Edwards and Newell (11), Baron (4, 5), McKenzie et al. (15), and Steuart (21) report on detailed analyses of airline arrivals and departures.] It should be emphasized that the patterns of transfers and peaks vary over time. As air traffic develops in a region and more direct flights become available, the number of transfers at some airports may decrease significantly, or they may increase. The introduction of aircraft with transcontinental ranges eliminated many of the stops and transfers that used to occur in Denver, but they also created Copenhagen's position as a gateway to transpolar flights from Europe to western United States.

The intensity of peaks in traffic can also change noticeably. They can increase for airports that develop greater vacation traffic and can decrease strongly for airports, like Los Angeles, that become destinations for more routine or business trips (Figure 8). Punctuality of aircraft may also improve as the facilities for air navigation and maintenance improve and may deteriorate as an airport becomes congested and delays build up. No firm rules on these trends can be established. We simply need to remain

Figure 3. Variations in 1973 monthly passenger traffic at New York and London airports.

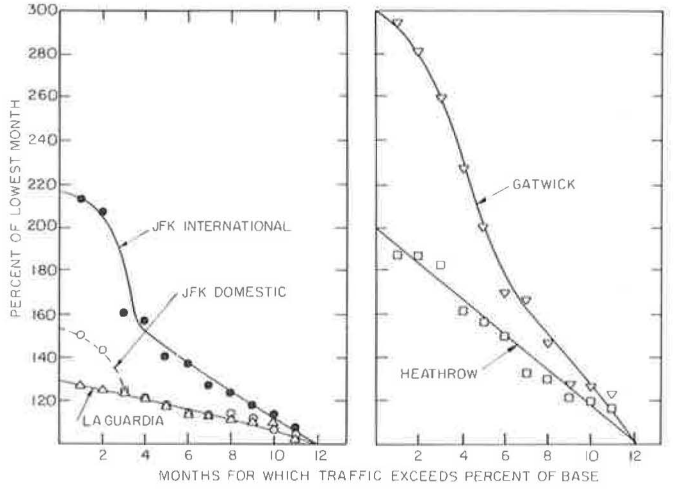


Figure 4. Variations in 1973 monthly passenger traffic in Zurich.

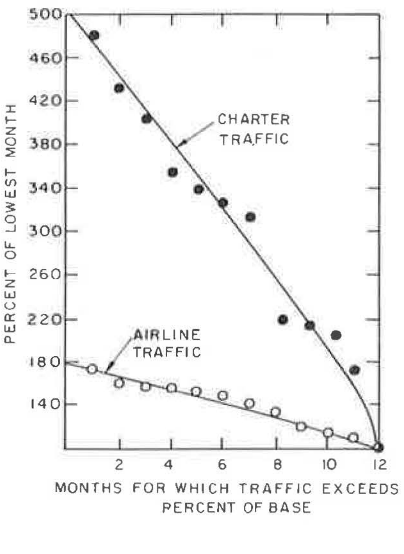


Figure 5. Examples of different kinds of daily fluctuations in traffic.

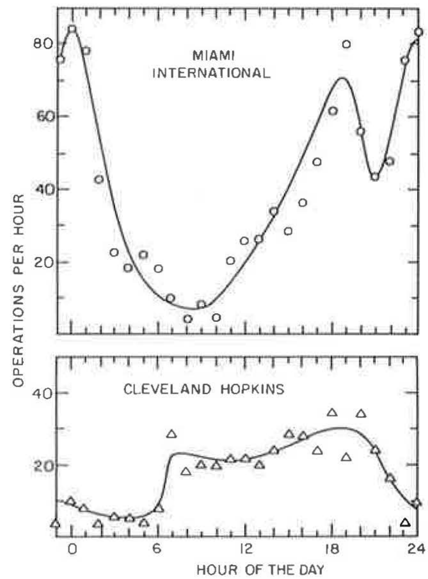
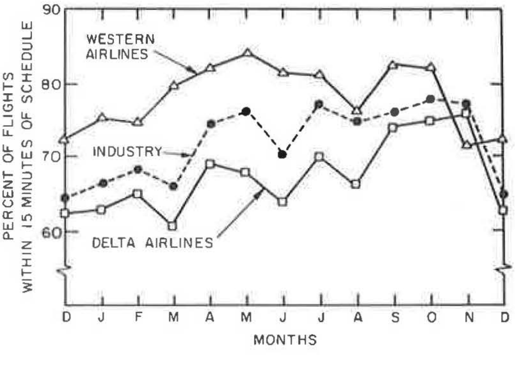


Figure 6. Variation in punctuality of 1973 airline arrivals and departures in the United States.



flexible and to design our terminals so that they can accommodate different kinds of traffic.

NATURE OF TERMINAL FACILITIES

With these data in mind, we can now examine the major questions concerning the fundamental nature of terminal facilities at an airport.

1. Should the facilities be centralized in a single major complex or decentralized into separate terminals or gates as with the gate-arrival concept?
2. Should transporters be used exclusively, as at Washington (Dulles) Airport, partially as at most European airports, or not at all?
3. Should the facilities be shared by different airlines, as they are in Europe and generally are not in the United States, and to what extent should they be shared?

Centralized or Decentralized

A centralized terminal facilitates transfers. It generally implies smaller distances for persons connecting between flights. This is not to say, of course, that the distances are necessarily short: From one end to the other end at Chicago (O'Hare) Airport is more than 1 mile (1.6 km). Large as this is, it is less than the comparable figure for a gate-arrival terminal: The greatest distance between gates at Dallas-Fort Worth, an airport with far less traffic, is more like 3 miles (5 km). Use of a central terminal also makes it possible to keep transfer passengers within a single building and thus reduce the number of security inspections that must be made. A central terminal can also provide an easy connection to a public transit system. The railroad station for the Frankfurt (Main) Airport is right below the central terminal building and curb, for example. But for an airport with decentralized terminals, such as New York (Kennedy), it is essentially impossible to locate stations that would be convenient to each unit.

A central terminal also creates congestion. This is both good and bad. It is good because traffic is heavy enough to support restaurants, shops, and other passenger conveniences. At gate-arrival terminals, where this density does not exist, passengers can hardly get anything to eat, for operators cannot afford to maintain the equipment and staff required to provide food service for the few persons who pass by a few gates. Conversely, however, the congestion at centralized terminals can delay and confuse traffic and is exactly the kind of inconvenience gate-arrival terminals are designed to overcome. Qualitatively, gate-arrival terminals are most convenient for commuting passengers who are going directly to some destination and who have little concern for transfers or for special shops and services; they probably want to proceed as quickly as possible to their flight.

From an economic point of view, the better configuration depends on the trade-off between the extra costs of providing more facilities with more personnel at decentralized terminals and the savings that occur by avoiding the costs of congestion in a centralized terminal. The extra costs of operating a gate-arrival facility can be quite high. This design requires separate check-in counters for every few gates and prevents staff from being used for many flights at once. Braniff and TWA each estimated, for example, that they needed 15 percent more staff to serve their new gate-arrival facilities at Kansas City. The special costs of a central terminal can be higher, however.

The complexity and the cost of the equipment required to sort bags and cargo in a large terminal are the most powerful economic incentives for decentralization. Complicated mechanisms may have to be provided to sort this traffic through the confusion of a central hall serving dozens of destinations. Strong diseconomies of scale exist in this process: Costs increase exponentially faster than the size of the terminal. Specifically, a recent study estimated that, for cargo facilities,

$$\text{Total costs} = \text{constant} \times (\text{size})^{1.16}$$

This disadvantage of large size exists even in the presence of significant economies of scale in the construction of buildings, thus emphasizing the tremendous cost of sorting packages. [Diseconomies of scale exist whenever costs increase faster than size, that is, when the exponent on the size factor is greater than 1.0 (9).] Figure 9 (8) illustrates this. Trading off the extra costs of gate-arrival terminals and the diseconomies of sorting processes in a central facility, one finds that gate-arrival terminals are marginally less expensive for many large cargo operations.

The situation is less clear for passenger terminals. Whether or when diseconomies of scale exist for these facilities is not known. But because we can rely on passengers to try to find their own way, minimal equipment will be needed to help them, and it is almost certain that the diseconomies of scale will be less for passenger facilities than for cargo terminals. This means that gate-arrival terminals probably lose their marginal economic advantage and that central terminals may be less expensive for passengers.

A hybrid terminal may be best for many situations. To meet the conflicting desires of different passengers for ease of access and of transfer and to keep costs within bounds may be most effectively done by including both the centralized and gate-arrival concepts in an overall design for a terminal. The gate-arrival section can serve heavy commuter traffic to a few destinations, and the finger piers can serve the remainder of the passengers. In practice, this is the formula that has successfully evolved at New York (La Guardia) Airport, where the shuttle passengers to Boston and Washington have their own gates. A similar design is planned for the new terminal at Calgary: There, the gate-arrival facilities will serve the commuter traffic to the provincial capital at Edmonton (Figure 2).

Transporters

Transporters become better than constructed gates when the rate of use for the facilities becomes relatively low. When equipment is used for only a few hours a day or a few months a year, it becomes relatively expensive per passenger, for the same fixed costs get prorated over fewer people. Constructed facilities are especially sensitive to this effect since almost all of their costs consist of the fixed amortization of the capital invested. The cost per passenger served does not increase so rapidly, however, when one uses transporters. Some of their costs can be avoided when use is low: Fuel and maintenance costs drop, and drivers need not be hired.

A schematic comparison of the relative costs of transporters and of constructed gates appears in Figure 10. Whatever the relative cost may be at full utilization, the exponentially rising cost per passenger of constructed gates makes it practically inevitable that transporters provide the cheaper alternative at the lowest rates of utilization.

Detailed analyses in the United States and England indicate that it is economically efficient to use transporters for a sizable fraction of the gates at a major airport. [The major public reference on this is the study by de Neufville et al. (10). Its conclusions are supported by numerous private studies, including those of the British Airports Authority.] Although the results depend both on local costs and variability of the traffic, serving about one-third of the aircraft positions with transporters typically appears to be best. Because these should be the gates with the lowest rates of utilization, they will only serve a small fraction—about 10 percent or less—of the total number of passengers through the terminal. Relatively few would thus have to face the delays of using transporters.

With regard to costs, the desirability of transporters depends on anything that influences the relative costs of capital. High interest rates make transporters more attractive, for example. But high inflation, which increases the cost of salaries and fuel and reduces the real cost of construction, favors constructed facilities.

Transporters are particularly useful as an addition to existing facilities in special

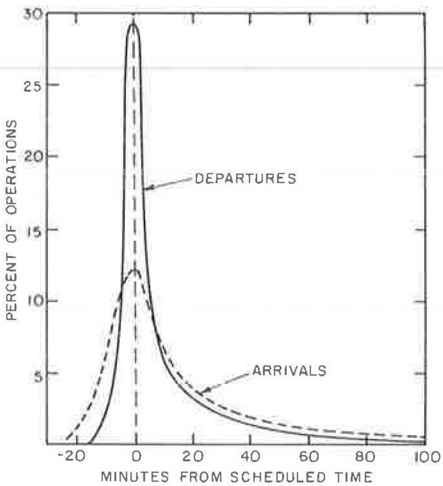


Figure 7. Typical variations in punctuality for arrivals and departures of aircraft.

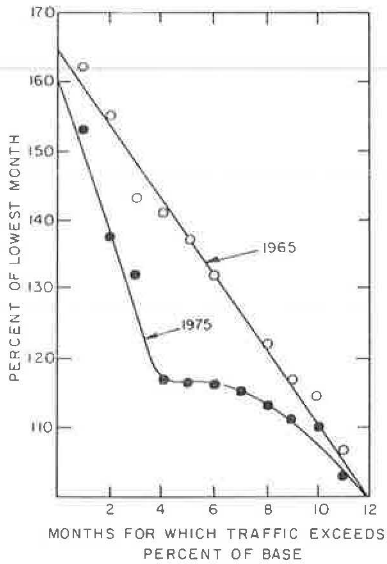


Figure 8. Variation in peaks of passenger traffic at Los Angeles International Airport.

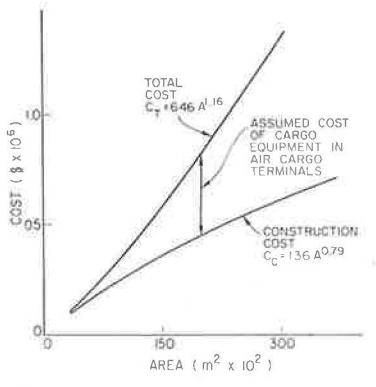


Figure 9. Diseconomies of scale in cargo terminals.

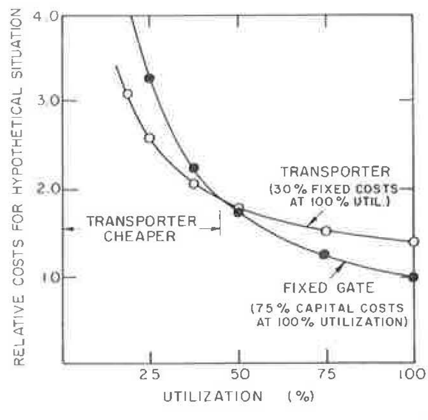


Figure 10. Relative costs and use of fixed and mobile gates.

Table 1. Existing and planned hybrid designs for airport terminals.

	Hybrid Terminals	
Concepts Blended	In Fact	By Design
Finger pier and transporter	Atlanta—Eastern and Delta use transporters	London (Heathrow), Paris (Orly-West)
Gate-arrival and transporter	Montreal (Mirabel)—Air Canada, others will use gate-arrival	Paris (de Gaulle)—Air France terminal
Finger pier and gate-arrival	New York (La Guardia)—Eastern's shuttle terminal functions as gate-arrival	Calgary—commuter service to Edmonton will be gate-arrival

circumstances that make constructed facilities particularly expensive or impossible to obtain. United Airlines currently estimates, for example, that transporters are desirable whenever the costs of constructed facilities exceed $3 million per gate. Because transporters can be acquired rapidly, they can also provide service to growth in traffic that occurs before constructed facilities are ready, as they have done at Toronto and New York (Kennedy).

Traffic patterns that lead to low rates of equipment use also favor transporters. They are thus especially advantageous for situations where there are significant peaks in traffic, either daily or seasonal. Likewise, they are relatively economical for airports at which arrivals typically deviate substantially from schedule. This frequently happens at facilities serving long-haul traffic, where small percentage changes in flight time translate into long delays.

Overall, a hybrid design including transporters is particularly appropriate when there are marked fluctuations in traffic or when expansion of constructed facilities is difficult. Some examples of this are given in Table 1. The transporters have proved to be effective in accommodating summer peaks of traffic, and are deliberately part of the plan at London (Heathrow) Airport and the prospective Air France terminal at Paris (de Gaulle) Airport. They also economically provide for rush-hour traffic on a daily basis and are used for this purpose at Paris (Orly-West) Airport, which is principally a domestic terminal, and at Montreal (Mirabel) Airport. The original plan at Montreal (Mirabel), incidentally, was to use transporters exclusively, but the domestic airlines appear to have persuaded the authorities to permit some use of transporters to meet immediate needs that cannot be filled by construction.

Shared Facilities

The size and cost of the facilities required can be reduced by arrangements to share their use among several airlines. This practice is commonplace in Europe and essentially everywhere else except in the United States. An airport authority typically operates the gates and other ground services for the benefit of everyone. Similar procedures for the nonexclusive use of gates by airlines exist in the United States at Honolulu and for various international terminals, such as the International Arrivals Building at New York (Kennedy) Airport. Many airlines in the United States also contract with other airlines to share the use of gates otherwise used exclusively by a single airline.

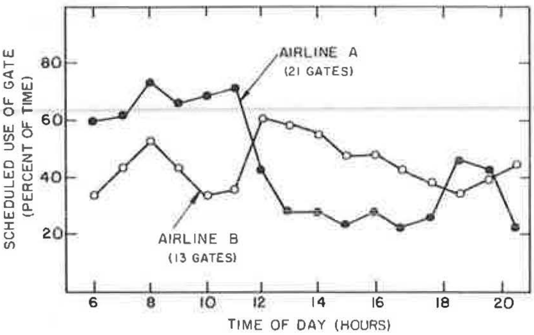
The advantage of shared use is that it allows more flights to be squeezed into any given number of gates. Essentially, the larger the number of operations to be served, the greater is the opportunity to manipulate the operations so that we can achieve higher use. This advantage is counterbalanced to some extent, however, by the difficulty of maintaining coordination among airlines, the expense of making equipment competitive, and the airlines' possible loss of image in competitive markets.

As indicated previously, the deviations from schedule that inevitably occur force us to provide more facilities than we would need if all went well. When a flight does not leave on time, an extra position may have to be provided to accommodate an arrival. Overall, this phenomenon may force us to install easily half again as many gates as would be needed if aircraft actually were able to perform on schedule. In practice, this number is estimated through a detailed examination of the activities anticipated at an airport. The essential features of the phenomenon are captured in the following approximate formula:

$$\text{Gates required} = (\text{gates needed by schedule}) + 2(\text{gates needed by schedule})^{1/2}$$

This is crude, but does emphasize that the extra slack that must be made available decreases, as a fraction of the total, for larger airlines or operating units. This is illustrated by operations at San Francisco. Figure 11 (6) shows that the largest airline

Figure 11. Scheduled use rate for gates at San Francisco.



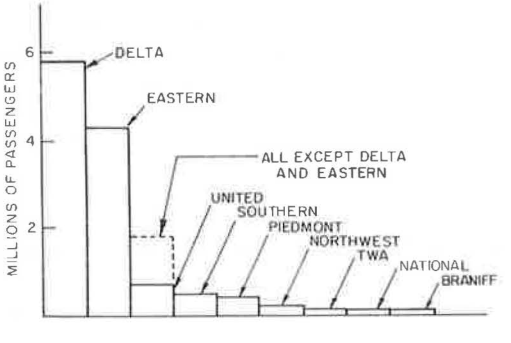
felt it could plan its activities around a 70 percent utilization at peak periods; the next largest apparently only dared go as far as a 60 percent rate. [Technically this formula presumes that deviations from schedule are distributed exponentially, such that the standard deviation equals the square root of the mean. The formula then defines the number of positions required to meet all demands 19 times out of 20. This formula is presented by Steuart (21). Others, by the Airborne Instruments Laboratory (2), Mogligevsky (16), and Stafford and Stafford (20), are discussed by McKenzie et al. (15). The study of San Francisco was done by Belshe (6).]

This behavior means that we can achieve considerable savings by combining several small operations into one common service shared by all. For example, if 4 airlines have a scheduled need for 5 gates each, they would require about 80 percent extra if acting separately, but only about 45 percent if acting together. A total saving of 35 percent would theoretically be possible for that case. Only relatively small savings might exist if we combine large operations. Joint use between 2 airlines requiring 40 gates each would lead to only a 10 percent reduction in facilities, an advantage that could easily be eliminated by other factors.

Further savings can be achieved through shared use when the airlines serve markets whose traffic peaks at different times. The effect depends on the degree of overlap between their needs. Figure 11 shows how demands of 2 major airlines can complement each other: At San Francisco the airline serving the eastern United States features many early departures to make for reasonable times of arrival in New York and elsewhere, but the airline going north-south needs the most gates after noon. To give some idea of what can be done, about a 15 percent reduction in gates at Paris (Orly-West) Airport was attained by effective sharing for airlines with different traffic patterns.

The major argument against some amount of joint use of facilities is not one of fact, since it is generally agreed that this approach can be economical, but one of principle. Airlines that compete against each other feel that they must be visible if they are to be successful. This implies that they want their own facilities. In Europe and many other places, this argument has little force because the airlines rarely compete. Quite the contrary, they are generally tied together by the so-called pooling agreements, according to which they pool their revenues and share them according to predetermined formulas. Outside of the United States, consequently, terminals are usually designed for shared use.

Figure 12. Passengers processed in 1974 by each airline at Atlanta.



Since airlines compete vigorously in the United States, they are unlikely to agree willingly to share gates and other major facilities. But there may be exceptions. A number of locations feature many small operations which, in fact, are hardly in competition. Such appears to be the case in Atlanta, for example, as shown by Figure 12. This is the kind of situation for which shared use ought to be considered, even in the United States.

PROCEDURE FOR CHOICE

The overall conclusion of this discussion is that we should plan to design terminals around combinations of centralized, decentralized, and transporter concepts. Arguments about which of these concepts is best—or should be adopted—are sterile if not vacuous. It is almost inevitable that a hybrid terminal of some degree is most suitable.

As a first step in determining what kind of combination makes sense for a particular site, we should try to gather the kind of data that will be helpful in deciding this issue. We should particularly attempt to define, especially since it is often not readily available, the pattern of variations in the traffic and the intensity of transfers, both between flights and for picking up cars and similar purposes.

Next, we should try to identify the approximate degree of hybridization that is most suitable for this location. To do this, we can apply the simple analytic models suggested in the preceding sections. We can first estimate the diseconomies of scale of central terminals, if any, and compare them with the costs of decentralization. Next, we can compare the local costs of transporters and fixed facilities and, by associating these data with information about the variability of the traffic, determine the proportion of transporters that appears reasonable. We can also use the formula provided to estimate whether the savings obtained through joint use of facilities are worthwhile. These analyses will certainly be crude, but they can be helpful in screening out the most desirable configurations.

Finally, we can use detailed analyses to investigate specific variations of the general configuration that appears best. At this point we can use the many factors that have been developed for sizing the specific dimensions that are necessary to service the kind of traffic that is expected. This is the level at which most terminal design has been carried out and is described in detail in standard references.

ACKNOWLEDGMENTS

The careful review of these ideas by many colleagues, notably by Robert Horonjeff, Adib Kanafani, Hanan Kivett, K. H. Schaeffer, and K. R. Whitehead, is gratefully appreciated, as is the support of the Institute of Transportation and Traffic Engineering of the University of California and of the Transportation Research Board.

REFERENCES

1. Statistiques de Trafic 1973. Aeroport de Paris, Direction Generale, Relations Internationales, Section Etudes Statistiques, Paris, April 1974.
2. Airport Terminal Plan Study. Airborne Instruments Laboratory, RDS-136, 1962.
3. On-Time Performance Reports. Aviation Week and Space Technology, various months, 1973.
4. P. Baron. A Simulation Analysis of Airport Terminal Operations. Transportation Research, Vol. 3, 1969, pp. 481-491.
5. P. Baron and D. Henning. The Passenger Terminal: A Systems Analysis Approach. Airport Forum, Vol. 4, No. 2, 1974, pp. 69-82.
6. R. D. Belshe. A Study of Airport Terminal Gate Utilization. Institute of Transportation and Traffic Engineering, University of California, Berkeley, graduate rept., 1971.
7. E. G. Blankenship. The Airport: Architecture, Urban Integration, Ecological Problems. Praeger, New York, 1974.
8. Report and Accounts for the Year Ended 31st March. British Airports Authority, London, June, 1974.
9. F. Chin, R. de Neufville, and J. Rebelo. Gate-Arrival Terminals: A Solution for Air Cargo? ASCE Transportation Engineering Journal, Vol. 101, No. TE, 1975.

10. R. de Neufville, H. M. Moore III, and J. Yaney. Optimal Use of Vehicular Systems in the Design of Airport Terminals. Civil Engineering Systems Laboratory, M.I.T., Cambridge, 1972.
11. J. W. Edwards and G. F. Newell. A Study of Gate Use at Honolulu International Airport. Transportation Science, Vol. 3, No. 3, Aug. 1969, pp. 183-191.
12. Amt fuer Luftverkehr. Flughafen Zurich: Jahresbericht 1973, Zurich, April 1974.
13. R. Horonjeff. Planning and Design of Airports. McGraw-Hill, New York, Rev. Ed., 1975.
14. 10-Year Summary of Air Traffic, 1965-1974. Los Angeles International Airport, 1975.
15. A. J. McKenzie, J. W. E. Huggett, and K. W. Ogden. Staging of Improvements to Air Transport Terminals. ASCE Transportation Engineering Journal, Vol. 100, No. TE4, Nov. 1974, pp. 855-872.
16. D. A. Mogligevsky. Siting and Design of Airports. English translation, 1965; National Technical Information Service, Springfield, Va., AD 622 357.
17. The Apron-Terminal Complex: Analysis of Concepts for Evaluation of Terminal Buildings. R. M. Parsons Company and Air Transportation Association of America, 1973; National Technical Information Service, Springfield, Va.
18. Airport Statistics Through December 1973. Aviation Economics Department, Port Authority of New York and New Jersey, New York, 1974.
19. R. Sommer. Tight Spaces: Hard Architecture and How to Humanize It. Prentice-Hall, Englewood Cliffs, N.J., 1974.
20. P. H. Stafford and D. L. Stafford. Space Criteria for Aircraft Aprons. ASCE Transportation Engineering Journal, Vol. 95, No. TE2, May 1969, pp. 237-243.
21. G. N. Steuart. Gate Position Requirements at Metropolitan Airports. Transportation Science, Vol. 8, May 1974, pp. 169-189.
22. U.S. Civil Aeronautics Board. Handbook of Airline Statistics. U.S. Government Printing Office, Washington, D.C., 1971 Ed., 1972.
23. U.S. Civil Aeronautics Board and Federal Aviation Administration. Airport Activity Statistics of Certificated Route Air Carriers, 12 Months Ended June 30, 1971. U.S. Government Printing Office, Washington, D.C., 1973.
24. Aviation Facilities Maintenance and Development. Hearings before the House Committee on Interstate and Foreign Commerce, U.S. Congress, Pt. 1, 91-22, July-Sept., 1969, pp. 175-183.