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Contents

Foreword

The eight papers in this volume focus on evaluating and improving the efficiency or quality of air transportation. Schwieterman sees the rapid growth of air cargo paving the way for development of a major express airline hub in the Asia-Pacific region. His evaluation of five criteria at eight sites concludes that airports in South China presently cannot satisfy all the criteria and that, almost by default, Manila emerges as the front-runner.

Allen and Vandebona describe potential cost savings achievable by introducing different levels of technological improvements in navigational capability. Cost estimates are determined through simulation methodology, and a comparison of the model with analytical work is provided. Conditions reflecting flow and network characteristics in the Pacific region are used, and the scope for substantial costs savings, even in such low traffic regions, is revealed.

Using Boston's Logan International Airport as an example, Barrett et al. offer a market-based approach to the problem of delay. Peak-period delay is predicted to be reduced by 10,000 hr annually, with about $13 million in savings to the airlines and an estimated value of $15 million in time savings for passengers.

Seneviratne and Martel present a set of indexes for evaluating the quality of air terminal service. They assume that quality is "comfort and convenience as perceived by the users" and propose a set of indexes for evaluation. These indexes represent several terminal characteristics and conventional level-of-service measures. The authors offer these quality-of-service evaluation tools for use in other multimodal terminals.

Ndoh and Ashford note the current impetus to move from quantified measures of service quality (e.g., capacity/volume or time/space) to those incorporating the perception of the passengers (i.e., more qualitative indicators). Suggested methodologies fail to adequately incorporate such indicators, and the authors explore the use of fuzzy set theory, particularly linguistic fuzzy set models, as a technique for evaluating service levels. A proposed approach for evaluating airport passenger services is given.

Gillingwater et al. base their paper on a systems analysis of the information requirements of a medium-size airport. A generic model of an airport information system, drawn from research at three European sites, is presented. The authors conclude that no currently available airport information system appears to meet the information requirements of medium-sized airports.

Prevedouros and Papacostas describe maximizing the use of existing operations data at the Honolulu International Airport to illustrate the wealth of analytical opportunities available by imaginative use of routinely collected data. They also present an innovative way of profiling airline operations.

Mohr and Gosling analyze the characteristics of door-to-door van service for the airport ground transportation system. They trace the evolution of this system, delineate the market niche, review passenger characteristics, and present a detailed intermodal comparison of vehicle miles, person minutes, and user cost for various party sizes. Management issues, information needs of the industry, and future research needs also are considered.

Express Air Cargo in the Pacific Rim: Evaluation of Prospective Hub Sites

JOSEPH P. SCHWIETERMAN

The rapid growth of the air cargo market is paving the way for the development of a major express airline hub in the Asia-Pacific region. Potential hub sites are evaluated using five criteria: capacity, location, local market size, terminal services, and route authority. The results illustrate that a South China hub would have immense locational advantages, saving an express carrier as much as $10 million annually in fuel cost. Of the eight sites evaluated, a hub in Hong Kong could serve the Pacific Rim with the fewest *flight hours* of service, whereas a hub in Taipei, Taiwan, could serve the region with the fewest *tonne kilometers* of service. Hong Kong also has the most lucrative local market, which minimizes the need for cargo transfers between flights and could save a hub operator $7 million annually in terminal costs. Airports in South China, however, currently cannot satisfy all the criteria for hub development. Terminal services remain particularly inadequate. Almost by default, Manila has emerged as the front-runner for the Pacific Rim hub—a development that could markedly affect airlines' operating efficiency and patterns of Asian trade.

The growth of the air cargo market is paving the way for the development of a major express hub in the Asia-Pacific region. Such a hub would improve significantly the reliability and speed of cargo service between Asian commercial centers. Five cities—Hong Kong, Manila, Shenzhen, Singapore, and Taipei—are leading contenders to become the dominant express hub.

This paper outlines the geographic and economic factors that will shape the development of this hub. The results show that a South China hub would have strong locational and commercial advantages over other sites. Many obstacles stand in the way of hub development in this region, however, leaving airlines little choice other than pursuing less-than-ideal locations for their hubs. This could markedly affect the efficiency of the hub operation itself as well as future patterns of Asian airborne trade.

This paper offers a background perspective on express cargo services and the global role of express hubs, outlines the economic benefits to metropolitan areas associated with the development of a local express hub, evaluates the strengths and weaknesses of eight potential hub sites, and discusses implications and conclusions.

BACKGROUND

Express cargo airlines are carving a growing niche in the freight market by providing faster, more convenient service than traditional air cargo operators. Called "integrators" because they vertically integrate air and ground services, express cargo airlines offer shippers guaranteed overnight delivery, door-to-door convenience, and computerized information systems—for which Asian shippers pay substantial premiums. Although express shipments account for only 5 percent of total tonnage in the region, they generate nearly 20 percent of air cargo revenues (*1*).

Two types of express carriers serve the Pacific Rim: *direct* carriers, which operate their own aircraft, and *indirect* carriers, which lease space on the scheduled flights of other carriers. Federal Express Airlines and United Parcel Service (UPS), both based in the United States, and TNT Express Worldwide, based in Amsterdam, The Netherlands, operate as direct carriers in the region. The region's largest indirect carrier, Hong Kong–based DHL International, transports most of its Far East cargo on passenger flights, even though DHL freighters directly serve many overseas markets. General cargo airlines, such as Cathay Pacific Airlines, Japan Air Lines, and Singapore Air Lines, also operate successful express businesses. Their services, however, tend to be relatively specialized, limiting their market share to about 5 percent (*2*).

Market Growth

Express shipments are growing in volume by 20 percent annually in Asia, compared with 5 percent in North America and 9 percent in Europe (*3*). In the Special Economic Zones of China, the volume of express shipments is more than doubling each year (*2*). By 2000, shipments throughout the Pacific Rim are expected to increase 300 percent, to 10 billion T-km annually (*3*). (A tonne kilometer is 1 T of cargo carried a distance of 1 km.) This will make the turn-of-the-century Pacific Rim market roughly the same size as the present U.S. express market.

Asia's expanding service economy and the proliferation of just-in-time inventory systems are expected to fuel most of the market growth. These developments are creating a need for "global sourcing" services—logistics, distribution, and warehousing support for multinational companies needing fast delivery of inventory and replacement parts. Anticipating rapid growth, for example, Federal Express recently established a global sourcing facility in Singapore as part of its Partsbank program. Not to be outdone, DHL is vigorously promoting a similar program, Interchange, throughout the region.

Express carriers do not limit their business to small parcels, replacement parts, and other types of door-to-door traffic. As much as 85 percent of their Asian cargo is airport-to-airport freight (*4*). At Federal Express, for example, daily flights often are filled with lower-priority cargo, much of it from customers predating the carrier's 1989 acquisition of Flying Tigers. Nevertheless, with their emphasis on "time-definite" delivery (i.e., strict adherence to a predetermined delivery schedule), express carriers are able to command higher prices than general cargo carriers.

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Countries throughout the region urgently need improved express services. The integrators' current system of shipping most inter-Asian cargo on passenger flights denies shippers the fast service they need for time-sensitive freight. Because of the daytime scheduling of passenger flights, some regional shippers seeking overnight delivery must drop off packages during the early morning hours of the preceding day. Between Jakarta, Indonesia, and Seoul, South Korea, for example, the deadline is 8:00 a.m. because the last direct flight between these cities departs at 11:00 a.m. In other markets, in which complex flight connections are involved, shippers have no access to overnight cargo service. Reliability also is affected by the frequent cancellations and delays associated with international passenger services.

Expanding Role of Express Hubs

Hub systems not only enhance speed and reliability but allow carriers to consolidate freight en route to many destinations onto a single plane, enabling them to use larger, more efficient aircraft. This characteristic will be particularly important for an Asia-Pacific hub operator, which will serve airports separated by long distances. (On the basis of data presented later in this paper, the average regional flight segment will be about 2300 km, compared with 1500 km from North American hubs.) Because of the need to use large aircraft, the Asia-Pacific market is expected to be large enough to support only one major hub during the next decade. Therefore, the development of a hub is an all-or-nothing proposition for regional airport authorities.

The possibilities for a Asia-Pacific express hub are exemplified in North America, where integrators now earn more than 60 percent of air cargo revenues. Since launching the first hub-and-spoke cargo system in 1973, Federal Express has expanded its operation to encompass more than 400 flights and 1.7 million packages daily, making it the world's largest express carrier (*5,6*). Aircraft depart from outlying destinations to arrive at Federal Express's Memphis "superhub" between midnight and 1:00 a.m. Within 2 hr, cargo is sorted in a specially designed terminal and reloaded onto planes bound for the shipments' final destinations. A fleet of 31,000 vehicles is available to deliver packages and other freight to customers' doors (*6*).

The world's four major express companies are in the process of building global hub systems. In Europe, for example, DHL operates a hub in Brussels and is developing a same-day delivery system in Germany with Lufthansa Airlines; Federal Express, rebounding from earlier setbacks in Europe, is developing a minihub operation in Paris; TNT is building a hub in Cologne, Germany; and UPS is developing an expensive ground-based delivery system throughout Western Europe (*2*).

Integrators also are preparing for major expansion in Asia through the following:

- Federal Express unveiled plans in November 1993 for a major cargo-connecting complex at Subic Bay Airport. This facility, recently vacated by the U.S. Navy, is 60 mi northwest of Manila and will initially serve three daily flights—probably new A300s. Nevertheless, the carrier emphasizes that Subic Bay is *not* necessarily its future Far East hub. It initially will be used to transload transpacific cargo, not to sort inter-Asia express shipments (*7*).
- TNT opened a minihub in Manila in June 1993 to provide overnight service between Taiwan, Singapore, the Philippines, and Brunei, using BAe-146 aircraft (*8*). The carrier is planning to expand this operation to 11 cities by 1995 and currently is negotiating with Hong Kong, Kuala Lumpur, and Bangkok for the necessary traffic rights. Many consider this to be a preemptive move intended to deter competitors from launching hubs of their own.
- DHL is making huge investments in major terminal facilities in Singapore and Japan and is opening express centers throughout mainland China (*9*).
- To keep pace with its competitors, UPS is purchasing new widebody aircraft to provide expanded service in the Asian market.

LOCAL HUB BENEFITS

The metropolitan area that becomes Asia's major express hub will reap several significant benefits.

First, it would receive improved cargo delivery schedules. A local hub would provide more attractive "closeout" times (i.e., terminal deadlines) and offer more nonstop service to shippers than an out-of-town hub. Shippers located in hub cities will be able to deliver cargo as late as 10:00 p.m. for overnight shipment, compared with deadlines of 5:00 p.m. in cities that are merely spokes for offshore hubs. A local hub also would help lower terminal rates and hasten the development of an advanced electronic data interchange system.

Second, a local express hub could cause dramatic reductions in air cargo rates. Relatively few carriers currently provide freighter service between major Asian markets (*2*). Studies by Gellman Research Associates (1990) and Schwieterman (1993) show that the entry of U.S. cargo airlines into concentrated intra-Asian markets could lower prices by at least 5 percent (*2,10*). These studies show that the annual benefits to shippers from heightened price competition could exceed $100 million (U.S.) in large metropolitan areas such as Hong Kong.

Finally, a local hub would provide substantial new revenues for the airport authorities through additional landing and parking fees. If the hub were to support 25 daily arrivals and departures, for example, it could generate $25 million to $32 million annually in such fees. [These estimates are based on a hub operating 6 days per week and generating aeronautical fees of $3,200 to $4,100 per departure (*2*).]

These aeronautical revenues would strengthen an airport's financial position. Even if an airport observes the rules of the International Air Transport Association (IATA) which prohibit airports from charging aeronautical fees in excess of long-run average costs, its fees will exceed marginal costs. In Hong Kong, for example, the airport authority expects operating costs at its new airport to initially offset just 30 percent of aeronautical revenues, and it will apply the remaining 70 percent of these revenues toward airport debt (*11*). Increased flight activity at the hub also will boost commercial revenues, franchise fees, and land rentals around the airport.

COMPARATIVE SITE ASSESSMENT

Airports in five cities—Hong Kong, Manila, Shenzhen, Singapore, and Taipei—are leading contenders to become Asia's dominant express hub. This section analyzes the strengths and weaknesses associated with these leading sites and compares them with those of Bangkok, Kuala Lumpur, and Osaka (Nagoya), which also are vying for additional express cargo business. Each hub site is considered on the basis of five technical criteria: airport capacity, location, size of the local market, terminal services, and route authority. The results show that hub sites in South China, particularly Hong Kong and Taipei, have decided advantages but must adopt new government policies if they are to remain serious hub contenders.

Airport Capacity

Each of the leading hub candidates has, or eventually will have, adequate capacity to support a major hub:

- In Shenzhen, China, located in the booming Pearl River Delta and only a short distance from Hong Kong, a new 24-hr international airport opened in October 1991 (*1*). A second runway is scheduled to open by 1997. Roads and other infrastructure near this airport, however, still are inadequate, rendering a major hub at Shenzhen infeasible for about 2 years.
- In the Philippines ample capacity exists at both Manila International Airport and nearby Subic Bay Airport to support a major hub. The international airport at Cebu also is attractive to express carriers.
- In Singapore, Changi Airport recently was doubled in size and eventually will expand to four terminals and three runways (*12*).
- In Taiwan capacity exists at Taipei's Chiang Kai Shek Airport to support a major hub. Officials are drafting plans to make the airport the leading transportation center in Asia, with three runways and one of the world's largest cargo terminals (*13*).
- In Hong Kong a new 24-hr, two-runway airport on reclaimed land around the island of Chek Lap Kok is scheduled to open in late 1997 (*11*). This will alleviate the severe parking space shortages, congestion, and nighttime curfews that limit cargo expansion opportunities at Hong Kong International Airport (Kai Tak).

Because of contractual disputes, there is growing concern that Hong Kong's new airport will not be finished until 1998—a costly delay that could prevent Hong Kong from participating in the early stages of hub development. Nevertheless, Hong Kong still could play a major role in a hub's later developmental stages. Express carriers could relocate to Hong Kong upon completion of Chek Lap Kok if that facility proves to be the best site and can avoid further construction-related delays.

New airports also are either under construction or already completed in Bangkok, Kuala Lumpur, and Osaka (*14*).

Location

Prospective hub sites differ markedly geographically. The following analysis considers the proximity of each hub site to 15 major Asian cargo centers: Bali, Indonesia; Bangkok, Thailand; Beijing, People's Republic of China (PRC); Guangzhou (Guangdong), PRC; Hong Kong; Jakarta, Indonesia; Kuala Lumpur, Malaysia; Manila, the Philippines; Osaka, Japan; Penang, Malaysia; Seoul, South Korea; Shanghai, PRC; Singapore; Taipei, Taiwan; and Tokyo, Japan (Figure 1). These cities are among the region's largest air cargo centers and represent all the region's major industrial powers.

To serve these cities with minimum flight costs [costs are measured using published IATA Great Circle distances (*15*)], the Asia-Pacific hub would have to be in the South China region—precisely where capacity shortages are most severe (Table 1, Column a). For example, the operator of a Hong Kong hub could serve these cargo centers with 28 683 km of flight service, compared with 30 552 km at a Taipei hub, 31 620 km at a Manila hub, and 39 031 km at a Singapore hub. (The Hong Kong and Shenzhen sites, separated by only about 100 km, are almost equally attractive.) This means that the operator with a hub in Hong Kong could serve the region's 15 largest markets with 6.2 percent fewer flight miles than with a Taipei hub, 10.2 percent fewer flight miles than with a Manila hub, and 36.7 percent fewer flight miles than with a Singapore hub. Clearly, Hong Kong and Shenzhen have formidable advantages of location.

Operating costs would differ vastly between hub sites. On the basis of average fuel costs of $2.60/flight-km [the average reported by Federal Express Airlines in 1992 (*16*)], a Hong Kong hub would save $2.4 million to $10.7 million annually relative to hubs outside the South China region (Table 1, Column b). By reducing the number of flight hours, crew expenses also would be reduced.

Flight distance, however, is not the only relevant criterion in evaluating a hub's location. Flights to certain markets, such as Tokyo and Seoul, will carry more cargo than those serving smaller markets, such as Bali or Penang. It is appropriate to weigh these larger markets more heavily in the analysis by considering the different number of tonne kilometers associated with each hub location.

If the amount of express cargo shipped to each destination is proportional to the destination's 1991 total air cargo throughput (see Table 2 for a discussion of the methodological approach), the hub would have to be 500 km east of Hong Kong to minimize total tonne kilometers. This shift occurs because markets in the eastern part of the region tend to be larger than those in the western part. The operator of a Taipei hub could serve the 15 major markets with 10.4 percent fewer tonne kilometers of service than with a Hong Kong hub, 28.8 percent fewer tonne kilometers than with a Manila hub, and 91.2 percent fewer tonne kilometers than with a Singapore hub (Table 2, Column a). Thus, a Taipei hub would have important logistical advantages, whereas Kuala Lumpur and Singapore would have inherent limitations as hubs.

Prospective hubs in South China are equally impressive with respect to *average travel distance*. Under the same set of assumptions, the average shipment would travel 3224 km from its origin to its destination using a Taipei hub and 3575 km using a Hong Kong hub (Table 2, Column b). By contrast, shipments using hubs in Manila and Singapore would travel 4141 and 6177 km, respectively. These differences are important because they show that the South China hub could cut travel times by as much as 5 hr per shipment (Table 2, Column c). For an operator with a Taipei hub, for example, the average travel time would be about 5½ hr per shipment, compared with 7 hr for a Manila hub and more than 10 ½ hr for a Singapore hub. Clearly, a carrier with a South China hub could offer customers the most attractive delivery schedules.

Political and economic factors, such as language, ethnicity, and economic growth, also will affect the demand for express cargo service. Moreover, the mix of cities to be served will affect the attractiveness of each prospective hub site. For example, if Southeast Asian markets such as Cambodia, Laos, and Vietnam were to be served, the hub would have to be about halfway between Hong Kong and Taiwan to minimize total tonne kilometers. Alternatively, if major cities of eastern India, such as Calcutta and Madras, were to be served, the optimal site would be about 200 km west of Hong Kong, near Hainan Island, China. Under most scenarios, however, the optimal hub location remains squarely within the South China region.

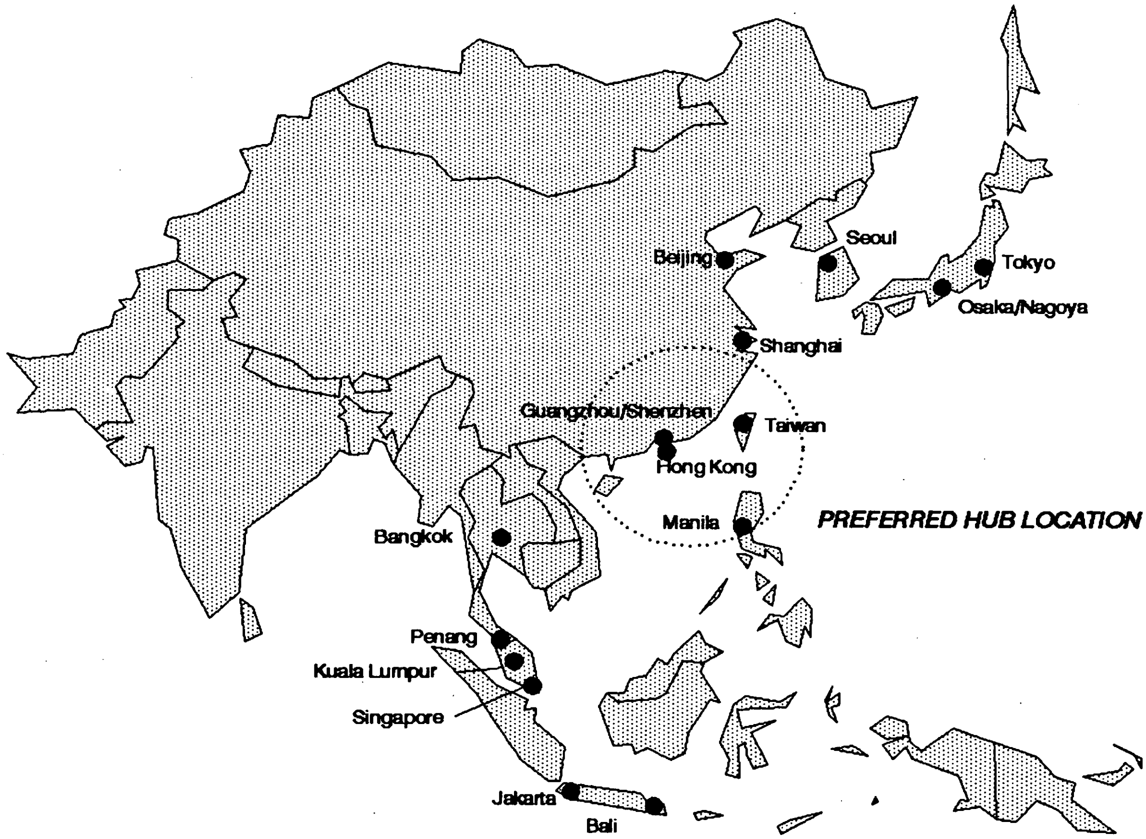

FIGURE 1 Major air cargo markets in the Pacific Rim.

TABLE 1 Cumulative Flight Distance by Hub

Hub Location	(a) Cumulative - Flight Distance - Kilometers*	Index*	(b) Annual Fuel Cost vs. Hong Kong (millions of USD)**
Hong Kong	28,683	1.000	--
Shenzhen	29,331	1.022	+$0.5
Taipei	30,552	1.065	$1.6
Manila	31,620	1.102	$2.4
Bangkok	35,667	1.243	$5.7
Kuala Lumpur	38,546	1.344	$8.0
Singapore	39,031	1.361	$8.4
Osaka	41,817	1.458	$10.7

* Flight distances to serve 15 major Asia-Pacific cargo destinations (IATA Great Circle distances). The index numbers are based on distances relative to a Hong Kong hub.

** Based on $2.60 fuel cost per flight kilometer.

TABLE 2 Cumulative Tonne Kilometers by Hub

Hub Location	(a) Cumulative Tonne kilometers (Index)*	(b) Distance Flown per Shipment (Kilometers)*	(c) Average Travel Time**
Taipei	1.000	3,224	5 hrs. 22 min.
Hong Kong	1.109	3,575	5 hrs. 57 min.
Shenzhen	1.140	3,675	6 hrs. 7 min.
Manila	1.288	4,141	6 hrs. 55 min.
Osaka	1.330	4,288	7 hrs. 8 min.
Bangkok	1.648	5,313	8 hrs. 51 min.
Kuala Lumpur	1.913	6,166	10 hrs. 16 min.
Singapore	1.916	6,177	10 hrs. 30 min.

* Based on a hub serving 15 major Asia-Pacific cargo destinations (IATA Great Circle distances). The amount of tonnage generated in each city is assumed to be proportional to that city's 1991 total air cargo throughput. This tonnage is distributed across each destination proportionally to the destination's 1991 air cargo throughput <17>.

** Based on Federal Express 1992 system average of 600 kilometers per hour.

Size of Local Market

Another important hub criterion is the size of the local market. When substantial business is generated locally, a greater proportion of the cargo can be shipped nonstop from its origin to its destination, thus lowering travel time as well as the costs associated with sorting, loading, and unloading cargo. A large local market also ensures the availability of passenger flights to carry cargo to lesser destinations where demand is too light to support freighters. The belly compartments of passenger flights typically can accommodate up to 10 T of cargo (*5*).

The local markets of the leading hub sites differ dramatically in size:

- Hong Kong's local market is vastly superior to that of the other hub sites. It has convenient highway access to China's Pearl River Delta and is the world's third largest air cargo market, with annual throughput that is expected to surpass 1 million T in 1994 (*1*). The operator of a Hong Kong hub would be able to carry nearly 13 percent of all shipments nonstop from origin to destination (Table 3, Column a). Hong Kong also has an extensive network of passenger flights with service to more than 30 international destinations (*5*).

By minimizing the number of shipments requiring flight connections, a Hong Kong hub could reduce terminal costs. On the basis of conservative assumptions given in Table 3, annual terminal costs at a Hong Kong hub would be between $2.2 million and $7.6 million lower than at the other sites (Table 2, column c). A Hong Kong hub also would minimize the costs associated with loading and unloading aircraft, which are not included in terminal fees.

- Singapore and Taipei also boast large cargo markets, with annual throughput of nearly 600 000 T and passenger flights to more than 25 international cities. A hub operator in one of these cities could carry between 8 and 10 percent of its shipments nonstop from origin to destination.

- Manila and Shenzhen currently offer smaller local markets, generating only about 200 000 T of air cargo annually. A hub operator in one of these cities would carry only 3 to 5 percent of its shipments nonstop (*17*). Whereas a Shenzhen hub could directly serve shippers in Hong Kong, enhancing the size of its local market, the willingness of express carriers to ship their cargo on the congested roads and rail links between these cities remains uncertain. Also, the limited scope of Shenzhen's passenger services, which currently serve only five international destinations, would discourage hub development in that city.

Express hubs can be viable at airports without large local markets. In the United States, for example, major express hubs have prospered in medium-sized markets such as Cincinnati, Ohio; Louisville, Kentucky; and Memphis, Tennessee (*18*). These, however, are among the largest cities that offer highly attractive geographic locations. Thus, while small markets such as Manila and Shenzhen may still be viable hubs because of their attractive locations, Bangkok, Kuala Lumpur, and Osaka probably will remain unattractive hub sites, offering neither large local markets nor exceptional locations.

Terminal Services

Terminals will play a decisive role in hub development. They often are the only link in a lengthy, worldwide distribution chain in which carriers cannot exercise complete control over service quality, therefore rendering the link susceptible to communication breakdowns, disputes, and delays. Carriers understand that the quality of terminal services can be guaranteed only when they operate their own terminals or work closely with outside terminal-service operators.

Terminals in Manila and Singapore could quickly accommodate a major express hub. In Manila carriers have been given considerable autonomy with respect to terminal services. Recently, for example, TNT opened a $4 million express terminal at Manila

TABLE 3 Relative Local Market Size by Hub

Hub Location	(a) % of Shipments Locally Generated*	(b) Annual Terminal Costs vs. Hong Kong (in millions of USD)**
Hong Kong	12.9%	--
Singapore	10.2%	+$2.2
Taipei	8.8%	$3.3
Bangkok	6.2%	$5.4
Manila	5.3%	$6.1
Kuala Lumpur	5.3%	$6.1
Osaka	3.6%	$7.5
Shenzhen	3.5%	$7.6

* Based on 15 major Asia-Pacific cargo destinations.

** Based on a hub handling 7.5 percent of intra-Asia cargo (the current share of tonnage handled by express carriers in the transpacific market), with annual total throughput of 400,000 tons. Assumes average terminal cost of $0.20 per kilogram.

International Airport to support its fledgling local operation. In Singapore express carriers jointly operate the Express Courier Center, which is a unit of Singapore Air Terminal Services. DHL holds the largest investment in this facility, which is ranked by shippers as among the most efficient in Asia (*9*).

Terminal arrangements are less attractive in Hong Kong, Shenzhen, and Taipei. In Hong Kong terminal services are provided exclusively by Hong Kong Air Cargo Terminals Limited—an arrangement that is unacceptable to express carriers (*1,19*). Hong Kong, however, has a chance to improve its terminal services. By early 1994 its airport authority will decide whether to award express carriers a license to operate their own terminal at Chek Lap Kok. Because of space shortages, express carriers are not optimistic that the airport authority will grant them this much-needed opportunity.

In Shenzhen there are plans to build a major terminal, the Express Cargo Center. Carriers also have been granted permission to build their own terminals. They remain reluctant, however, to make such investments because of logistical issues associated with doing business in mainland China. Adequate terminals remain at least 2 years away.

In Taipei carriers must use the services of a government-owned terminal provider, Chaing Kai Shek Terminal Services, which is presenting serious problems for Federal Express and other carriers. Customs services are too slow and operating procedures too inflexible to support a major hub. Taiwanese officials repeatedly have denied Federal Express permission to build its own terminal.

Until governments in Hong Kong and Taipei give carriers opportunity to participate more directly in local terminal services, Manila and Singapore will retain this important advantage. Only officials in Shenzhen appear committed to closing this gap soon.

Route Authority

Finally, the legal authority to launch new flights within Asia is necessary for hub development. Although the bilateral issues affecting cargo airlines are discussed extensively elsewhere (*20,21*), their essential characteristics can be summarized.

Regardless of where the hub is located, governments will need to negotiate new Fifth Freedom Rights, giving carriers the right to carry passengers or cargo between two foreign countries. The outlook in negotiations for new Fifth Freedom Rights is favorable for hubs in Manila, Shenzhen, Singapore, and Taipei because of the amicable relationships between overseas air service negotiators and the respective national governments of these cities. Many U.S. cargo airlines already enjoy virtually unrestricted access to airports in Taipei and Singapore (*2*). For a major hub to be possible in Taipei, however, officials in Beijing and Taiwan must reach new broad-based agreements so that carriers can offer nonstop services between Taiwan and mainland China, which currently are forbidden. Such agreements are expected soon.

A bitter relationship exists between U.S. negotiators and Hong Kong. The U.S. government has dim hopes that it will be able to negotiate additional rights for Federal Express and UPS in the near future (*20*). Although the Hong Kong government may be forced to reconsider its policy as the debt for its new airport mounts, attempts to resume the bilateral discussions with the United States that abruptly ended in early 1992 have experienced difficulties. This could thwart Hong Kong's bid to become a major express hub.

CONCLUSIONS

With rapid growth in the Pacific Rim, a major express hub appears imminent. Such a hub will fill an important market niche, allowing carriers to collect packages in the early evening and guarantee their delivery to destinations in Asia the following morning. The leading hub candidates are listed in the following, roughly in descending order according to their prospects of becoming a hub:

- *Manila.* Almost by default, Manila has emerged as the frontrunner for the hub. It performs above the average, though not spectacularly, for all five criteria. Manila's efforts already are paying dividends as Manila becomes the focal point of the expansion plans of TNT and Federal Express. Political unrest in Manila and the country's struggling economy remain the primary disadvantages of a Philippine hub.

- *Taipei*. Taipei offers a large local market, liberal air service agreements, and available airport capacity. The operator of a Taipei hub could serve the region with the fewest tonne kilometers of service. For Taipei to become a viable hub site, however, policy makers must liberalize the market for terminal services, which is controlled by the government. Little progress on this front is expected in the near future.
- *Hong Kong*. Hong Kong offers an immense local market with convenient ground access to mainland China and an excellent geographic location. A hub in Hong Kong could serve major Asian markets with the fewest flight hours of service. However, Hong Kong must overcome three glaring deficiencies—curfews and capacity shortages at its existing airport, inadequate terminal facilities, and restrictive air service agreements—before it can become a serious candidate. Hong Kong will have to take steps to encourage express carriers to postpone their hub development plans until at least 1997, when Chek Lap Kok is scheduled to open. This will require awarding new Fifth Freedom Rights and authorizing express carriers to build their own terminal facility at the new airport.
- *Shenzhen*. Shenzhen's excellent location and eagerness to provide quality terminal services may not be enough to overcome the small local market and poor infrastructure around its new airport. Its proximity to Hong Kong could provide hub operators with convenient access to an immense local market, but the absence of passenger flights will remain a pressing problem.
- *Singapore*. Changi Airport in Singapore is attractive in all respects except for its remote location, which would require highly circuitous flight routings. Singapore's best hope may lie in marketing itself as a smaller hub that would focus on the Southeast Asian market.

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Modeling of Airspace Under Future Air Navigation Systems

DAVID R. ALLEN AND UPALI VANDEBONA

Potential cost savings that can be achieved from the introduction of various levels of technological improvements in navigation capability are described. Cost estimates are determined through simulation methodology. The simulation model, designed to measure conflict levels and costs associated with resolving conflicts in procedural airspace, optimizes levels of separation for particular flow rates. Comparison of the simulation model with analytical work found in the literature also is provided. Flow and network characteristics that reflect conditions in the Pacific region have been used in the simulation model to investigate a number of futuristic operating strategies for regions with relatively low air-traffic flow. The scope for substantial annual cost savings, even in such low-traffic regions, is revealed.

During the next decade, technological improvements within the aviation industry in the areas of surveillance, navigation, and communication technology are anticipated to lead to substantial cost savings. These cost savings are expected to be derived from improved air traffic flow and reduced track deviations.

This paper examines a methodology for estimating potential savings that can be expected from improvements to the navigational capability of aircraft operating in procedural control areas (nonradar surveillance environments). The improvement in navigational performance will be derived from direct surveillance through the automatic dependent surveillance (ADS) system, nonlocalized navigation enhancement gained from the global positioning system (GPS), and more reliable and accurate data transmissions via communications satellites.

The proposed methodology is focused toward estimating the effects of different minimum separation standards on system performance. These minimum separation standards correspond to different levels of technological enhancement as compared with the current state of technology. The attributes of the model's output are conflict-related specifically for category and frequency of conflicts. These attributes then are translated into a dollar value as a function of the minimum separation. The cost function then is investigated from an optimization point of view to determine the appropriate level of technology for a given flow rate.

The airway systems are modeled under different separation minima through a simulation program developed by the principal author. The simulation program is validated initially through comparison with conflict models already found in the literature.

BACKGROUND

This research project considers procedural airspace, or airspace for which the introduction of ADS and GPS will have the maximum effect. The ADS system offers to provide air traffic control (ATC) a pseudo radar environment in which the positions of all aircraft would be relayed via satellite to a regional control center. This pseudo radar environment will allow detection of certain types of way-point insertion errors, ATC errors, and deviations from the expected heading (*1*).

The certification of GPS the only navigation device will allow, in conjunction with inertial navigation systems (INS), a higher degree of positional accuracy. A single GPS set can provide readings accurate to 100 m for civil receivers (*2*). In addition, GPS offers higher system integrity than with the current inertial navigation systems.

In communications, satellites will allow for clearer and more reliable transfer of information for voice and data transmissions. This communication system will replace the high frequency radio system that currently is used to convey position reports.

These improvements in technology eventually will lead to raised safety levels and overall system confidence and integrity. As a consequence, measures can be undertaken to reduce costs for airlines and civil aviation authorities through the reduction in separation minima and the increased flexibility of airspace usage, ultimately allowing for more direct routing of aircraft.

SIMULATION MODEL

The simulation model developed at the University of New South Wales is designed to follow all aspects of the operating behavior of aircraft in procedurally controlled en route airspace. The procedurally controlled areas are defined by the region between the entry and exit points at the boundary of terminal airspace. "Terminal airspace" in this paper describes the area of airspace centrally located at airport nodes where aircraft are under direct radar surveillance. Aircraft operating within the boundary of terminal airspace are disengaged from the simulation phase because the terminal airspace environment entails different operational rules to procedural airspace.

The simulation model dispatches aircraft according to a stochastic method, with built-in allowances for departure delays. The program is linked to the Programmer's Hierarchical Interactive System (PHIGS) library for supporting graphics and therefore is able to display the location of the aircraft on a continually updated animation display. Furthermore, the traditional form of file output allows the retrieval of operating features of the simulated system in numerical, tabulation form. This particular output contains position, flight level, velocity, proximity, rate of fuel burn, weight, track deviations, and other factors as required at specified time intervals.

Simulated aircraft operating in procedural airspace are subject to a detailed examination on every update to determine relative position to other aircraft within a three-dimensional framework. This process allows the identification of a potential conflict or conflict in

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progress. A conflict is identified as the entry of one aircraft into the volume of protected airspace surrounding the neighboring aircraft. This protected volume of airspace has a regulated magnitude; this paper uses a cylinder of radius S_r and height S_z for the shape. Figure 1 shows the geometrical configuration associated with the analysis of a potential conflict. R_i and R_j are the spherical radii for each aircraft (it is assumed that the earth is spherical). These radii give the z-coordinate in the three-dimensional setup.

It can be proven that a conflict has occurred when the following two conditions have been met:

$$l_\gamma < S_r$$
$$|R_i + R_j| < \frac{S_z}{2}$$

where l_γ is the spherical distance between any two aircraft, i and j. The approximate expression for l_γ is derived as follows:

$$l_\gamma \approx \frac{1}{2}(R_i - R_j)\cos^{-1}\left(\frac{\overrightarrow{OA_i}\cdot\overrightarrow{OA_j}}{R_iR_j}\right) \quad (1)$$

where A_i and A_j are the positions of Aircraft i and j, respectively.

Once a potential conflict, or an actual conflict, is identified, it sometimes is necessary to modify the operating variables of one or both aircraft to ensure that the conflict does not occur and the risk of collision is eliminated. The process of resolution as carried out in the simulation model is shown in a simplified flow diagram in Figure 2.

The resolution modules within the simulation model are designed to follow the response of air traffic controllers to potential conflict situations. This is done by simulating future relative positions of aircraft by a period of t_p. Such responses direct velocity change, flight level changes, or route deviations. The effects of these directives are different for individual aircraft depending on the type of potential conflict.

For every conflict, the simulation model estimates the relative costs associated with each possible resolution. Factors included in this resolution cost comparison are listed as follows:

1. Length of sector remaining,
2. Cost associated with climbing and descending,
3. Cost associated with continuing remaining sector at the resolved altitude and velocity, and
4. Distance penalty associated with path change.

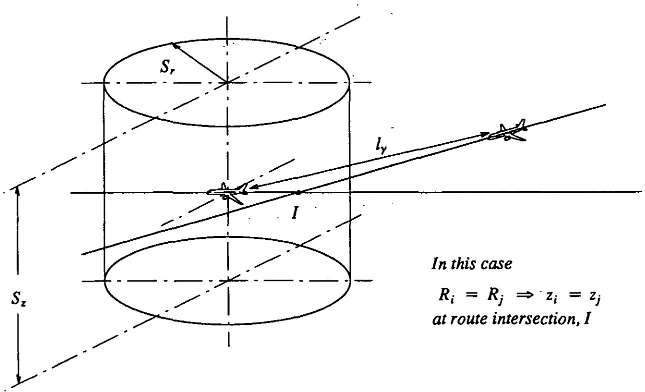


FIGURE 1 Forbidden volume surrounding aircraft.

The resolution choice with the lowest associated cost is carried out following a check to ensure that the resolving action does not precipitate further conflict.

The resolution costs of all conflicts of all aircraft are then added to obtain the total cost. The various cost components covered in conflict resolution are described in the next section.

COST FUNCTION

The cost function adopted in the model encompasses the main cost components involved in operating an aircraft along a particular stage. Three elements have been identified as forming the basis of the main cost components: (a) ground cost, (b) en route cost, and (c) stepping cost.

The ground cost component evolves from delay incurred at point of departure due to traffic congestion en route. The departure of the aircraft is postponed until airspace separation standards are available at the takeoff point. Delays of this form are usually the result of a like aircraft operating along the same track as that desired by the following aircraft. For the purpose of this analysis, it is assumed that airport congestion is not the critical link in the departure sequence of aircraft. The program can be modified readily to input airport-congestion–associated delays from other models.

The en route cost component covers those additional expenses that occur because of unplanned en route events such as conflict resolution and weather diversion delays. For most flights this component is likely to be the most critical of the three components. The constituents of this cost component are described later in this section.

The final component to consider in the cost function is the stepping cost. This cost is associated with an aircraft having to operate at a nonoptimum level because of the lack of "space" at the desired level. Aircraft that are unable to operate at optimum altitude generally have a cost disadvantage because of the higher rate of fuel consumption.

Together, these cost components can be expressed as

$$C_s = f(\text{ground, en route, stepping}) \quad (2)$$

where C_s is the cost to the system.

Each of these cost components, however, has associated factors that dictate the related cost. These associated factors are aircraft engineering (maintenance), passenger delay, crew charges, scheduling, and fuel burn. These factors are outlined partly by Attwooll (3).

Assuming that the function given in Equation 2 is first-order linear form, and that the average cost for each aircraft allows for a better base index, Equation 2 can be rewritten to find the mean cost ($\overline{C_s}$), as given in Equation 3:

$$C_s = \frac{1}{n}\left[\sum_i^n C_{G_i} + \sum_i^n C_{E_i} + \sum_i^n C_{S_i}\right] \quad (3)$$

where the expressions for C_{G_i}, C_{E_i}, and C_{S_i} are calculated by accumulating relevant cost factors for the ith aircraft. The number of aircraft is n. The association of these cost factors to their relevant group is given in Figure 3.

The fuel burn and engineering factors are excluded in the delay costs because both factors are dependent primarily on flying time; the other factors are dependent merely on time.

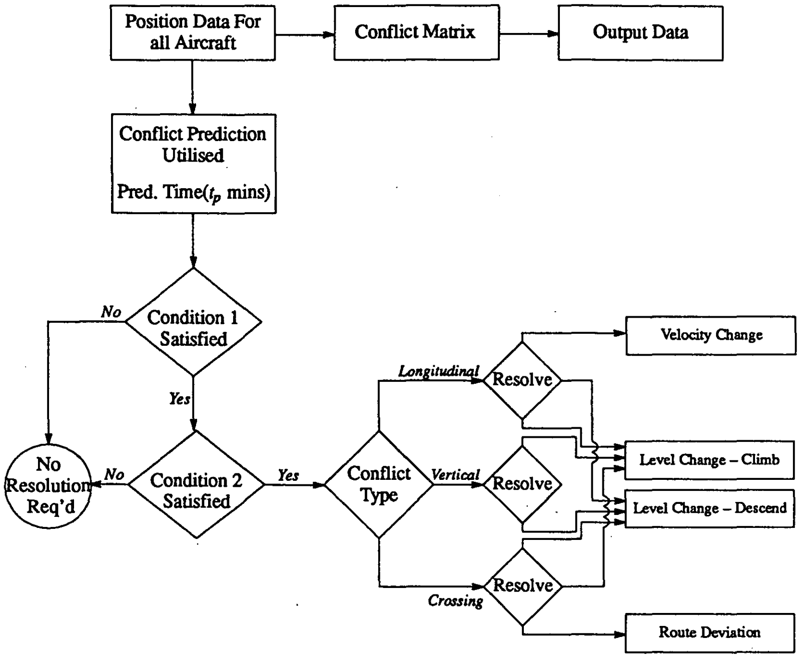


FIGURE 2 Resolution process in simulation program.

The inclusion of only the fuel burn variable in determining the costs associated with failure to step up a level is based on the negligibility of other factors compared with the extra fuel consumption. This is due to the insignificant time delay produced as part of the inability to step.

One other cost factor not addressed so far relates to the ADS update. The update rate will be dependent on separation minima and, to some degree, flow densities. The update rate will vary according to these parameters, thereby providing the controllers adequate information to safely process the passage of aircraft through the particular sector. The degree of ADS update also is influenced by the level of minimum separation. For low separation minima and high densities, the update rate could be near 10 updates per minute, therefore making it close to that for radar coverage of en route sectors.

An important factor that limits the application of the maximum update rate is the cost associated with operating at such a high update rate. It is anticipated that the cost of using the communication satellites will be about \$0.65 (U.S. dollars) per message update. This cost is related to the size of the information block being sent. Because of this, the update rate needs to be considered in any system cost function. The cost function from Equation 3 now can be expanded to include the cost of the ADS update as well:

$$\overline{C}_{S\text{ADS}} = \frac{1}{n}\left[\sum_{i}^{n} C_{G_i} + \sum_{i}^{n} C_{E_i} + \sum_{i}^{n} C_{S_i} + \sum_{i}^{n} C_{\text{ADS}_i}\right] \qquad (4)$$

where

$\overline{C}_{\text{ADS}_i} = (f_{\text{ADS}} t_i U_{\text{ADS}})$,
C_{ADS_i} = cost function (\$)
f_{ADS} = ADS cost factor (\$/message),
t = time (time unit), and
U_{ADS} = update rate (message/time unit).

MODEL VALIDATION

With simulation programs it is important to validate the output to ensure that the simulation is behaving in the designed fashion. With the simulation program developed here, it is impractical and extremely difficult to collect the data necessary to validate the operational side of the simulation. Therefore, model validation is attempted through comparisons with established analytical models. Many authors have developed basic analytical relationships between conflict and separation. Several authors have demonstrated conflict models, each with some degree of agreement(*4–9*). The Schmidt model (*6*) has been used for comparison with the present simulation model because it reflects the general basis of the governing relationships for conflict analyses.

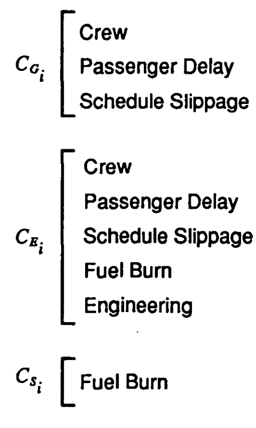


FIGURE 3 Cost factors.

The equation for the conflict model is given in Equation 5, where $E(N_c)$ is the expected number of conflicts per hour and f_1 and f_2 are the respective flow rates along the crossing tracks.

$$E(N_c) = \frac{2\, S_r f_1 f_2 (v_1^2 + v_2^2 - 2v_1v_2\cos\alpha)^{\frac{1}{2}}}{v_1 v_2 \sin\alpha} \quad (5)$$

The velocities of aircraft on Routes 1 and 2 are v_1 and v_2, respectively, and are assumed to be constant. The angle that separates the two airways is α. Schmidt's model evaluates the expected number of crossing conflicts for a two-route, single-intersection system.

Results for the theoretical model have been compared with the output obtained from the simulation model. Velocities v_1 and v_2 are considered constant and equal to 500 kn, with $\alpha \approx 27$ degrees. The arrival distribution for both the simulation and theoretical models is assumed to be a Poisson distribution. Schmidt assumes that S_r is composed of the regulation separation minimum and a further distance value to accommodate the controller's perception of a conflict. The additional distance value is assumed to be 0 for this exercise. A comparison of the theoretical and simulation models is shown graphically in Figure 4; there is little difference between the results obtained from the two models.

FIGURE OF MERIT

With the introduction of ADS, it will be necessary to maintain an update not only on the aircraft's position but also on the aircraft's navigational capability, so that the merit of the position report can be considered adequately. The field of data sent with the position report is called the figure of merit (FOM) and is composed of (a) an indicator of navigational equipment redundancy and (b) an indicator of position-fixing accuracy of the on-board navigation equipment (*10*).

FOM has been divided into eight levels of merit. These eight levels reflect the quality of the navigation: Level 0 represents the complete loss of navigational function whereas Levels 1 through 7 reflect an increase in navigation capability from a poor level to a high level of accuracy. Each FOM has a stated degree of positional accuracy that is based on a 95 percent containment within the boundary of allowable positional error.

These boundaries of allowable positional error are derived from the expected positional inaccuracy associated with aircraft operating under different combinations of navigation systems and sector length. In addition, the status of the aircraft's FOM is dynamic in such a way that it can change as conditions alter or navigational capability reduces. FOM therefore allows degradation of position reporting to be compensated for by the air traffic controllers in charge.

A simplified method for estimating the magnitude of the protected volume is given elsewhere (*10*). This protected volume often is represented as a rectangular prism, defined by longitudinal, lateral, and vertical separation minima. Variables are taken and applied to a simple root-sum-square procedure. The variables used in this paper for this procedure are as follows:

Ψ_1 = FOM (n.mi)
Ψ_2 = clock error = 10 sec ≈ 1.3 n.mi
Ψ_3 = longitudinal error = $U_{ADS}/3$(n.mi)
Ψ_4 = message time = 15 sec ≈ 2 n.mi
Ψ_5 = intervention time = 5 sec ≈ 0.7 n.mi
Ψ_6 = display errors = 5 n.mi

In the procedure time units are converted to distance units by assuming an aircraft speed of 480 kn. For this paper, longitudinal and lateral separations are taken to be of equal magnitude. This equality is achieved by adopting a variability in aircraft heading of 2.5 degrees, a value possible under an ADS environment.

The Ψ_5 variable is obtained by estimating the longitudinal error required before an alerting message is sent.

For different FOM levels, the value of S_r can be determined as follows:

$$S_r = (\Psi_1^2 + \Psi_2^2 + \Psi_3^2 + \Psi_4^2 + \Psi_5^2 + \Psi_6^2)^{\frac{1}{2}} \quad (6)$$

Table 1 presents containment values for each FOM, the related longitudinal minimum separations that will be used in this paper, and the relevant ADS update rates for each FOM. The value of the ADS update is based on equating the two main variables from Equation 6, namely, Ψ_1 and Ψ_3. The ADS update rate, therefore, is simply $\Psi_3 = 3\,\Psi_1$. This gives an update that increases proportionally as the separation distance reduces to a small value which is in accordance with expectations.

FOM A is an arbitrary level included for illustrative purposes. The separation minima associated with FOM A generally have a lower separation value than is used currently. Separation is approximately 10 to 15 min of longitudinal separation, or about 80 to 120 n.mi depending on the aircraft's velocity. The cost savings presented in this paper therefore are conservative figures.

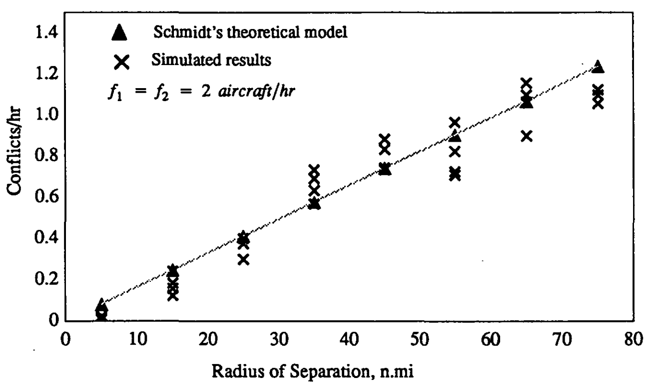


FIGURE 4 Comparison of simulation and theoretical models.

TABLE 1 Containment Values and Related Minimum Separations

FOM	95% Containment Value (n.mi)	ADS Update Rate (mins)	Min.Sep. (S_r) (n.mi)
A	N.A.	150	80
0	–	–	–
1	30	90	42.8
2	15	45	21.9
3	8	24	12.6
4	4	12	7.9
5	1	3	5.8
6	0.25	0.75	5.6
7	0.05	0.15	5.6

THE NETWORK

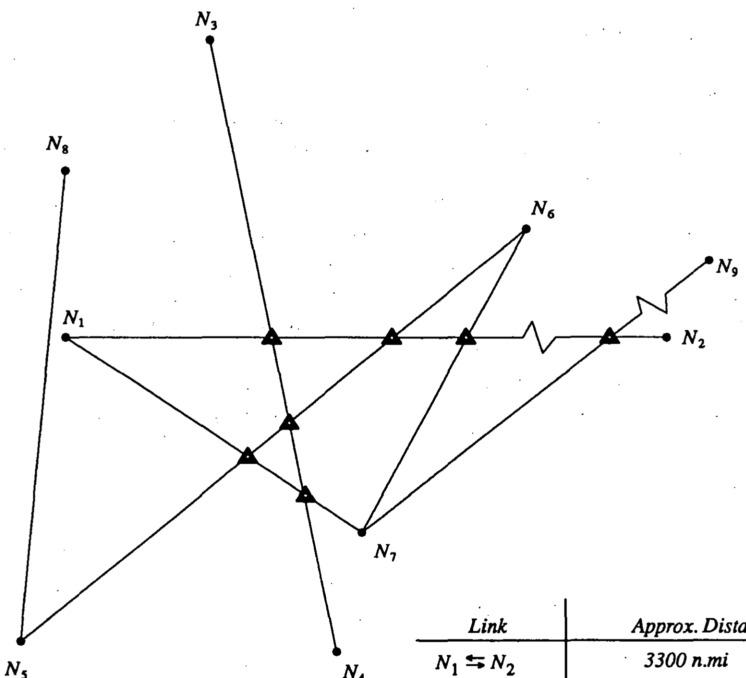
Cost savings, feasible under different FOM levels, are investigated using the simulation model already described. The simulation results presented in the next section are drawn from a nine-airport node network connected by seven airport-to-airport links. The links allow bidirectional air-traffic flow. The airport node layout represents the regional area that covers the Tasman and South Pacific oceans. Reference to actual airports and stages are avoided deliberately because many local features are not incorporated in the network presented here. It is best to consider the specified network as a simplified model (or representation) of a selected number of routes in the Pacific region. Figure 5 presents the network layout used in this paper and lists route distances to indicate the scale of the network.

RESULTS

The input data used for aircraft operating costs are drawn from information obtained from a commercial software package (*11*) and the operation flight manuals of the major aircraft operators of medium-length routes across the Pacific. Shown in Figure 6 are the average costs for all aircraft under different flow rates for different FOMs. Each symbol in the graph represents one simulated operation under the relevant operating parameters. It is encouraging to note that for FOM 1 through FOM 7 the standard deviation of the cost derived from the four simulated operation sessions is relatively low. However, FOM A does show a marked increase in the standard deviation of the cost estimate, particularly for high flow values. This change in standard deviation does appear to indicate a greater variability of results for large values of allowable minimum separation. An increased number of simulation sessions potentially would increase the level of confidence of the mean value of cost at these high levels of separation.

The regression analysis performed supports a linear relationship between the overall cost and the flow rate. According to these linear relationships, FOM A shows a significant increase in average cost for relatively large flow rates. As expected for FOM 1, FOM 2, FOM 3, and FOM 4, the trend is decreasing cost at a given flow rate. FOM 5, FOM 6, and FOM 7, however, reverse this trend with a general increase in average cost at a given flow rate. It is important to note the horizontal nature of the curves in the last three regimes already mentioned, for this characteristic indicates that Equation 4 is unresponsive to the flow variable for these operating regimes. The reason for this unresponsiveness is that, in these operating regimes, the ADS update cost (C_{ADS_i}) overwhelms the other cost components in Equation 4. Within these operating regimes, the relatively small separation standards involved significantly reduce the number of conflict events. Therefore, contributions from the other variables in Equation 4 are reduced in magnitude. For low flow rates and high FOM, Equation 4 can be reduced to

$$\overline{C}_{S_{ADS}} = \frac{1}{n} \sum_{i}^{n} C_{ADS_i} \qquad (7)$$



Link	Approx. Distance
$N_1 \leftrightarrows N_2$	3300 n.mi
$N_1 \leftrightarrows N_7$	1200 n.mi
$N_3 \leftrightarrows N_4$	2200 n.mi
$N_5 \leftrightarrows N_6$	2100 n.mi
$N_6 \leftrightarrows N_7$	1200 n.mi
$N_5 \leftrightarrows N_8$	1800 n.mi
$N_7 \leftrightarrows N_9$	4600 n.mi

FIGURE 5 Network layout.

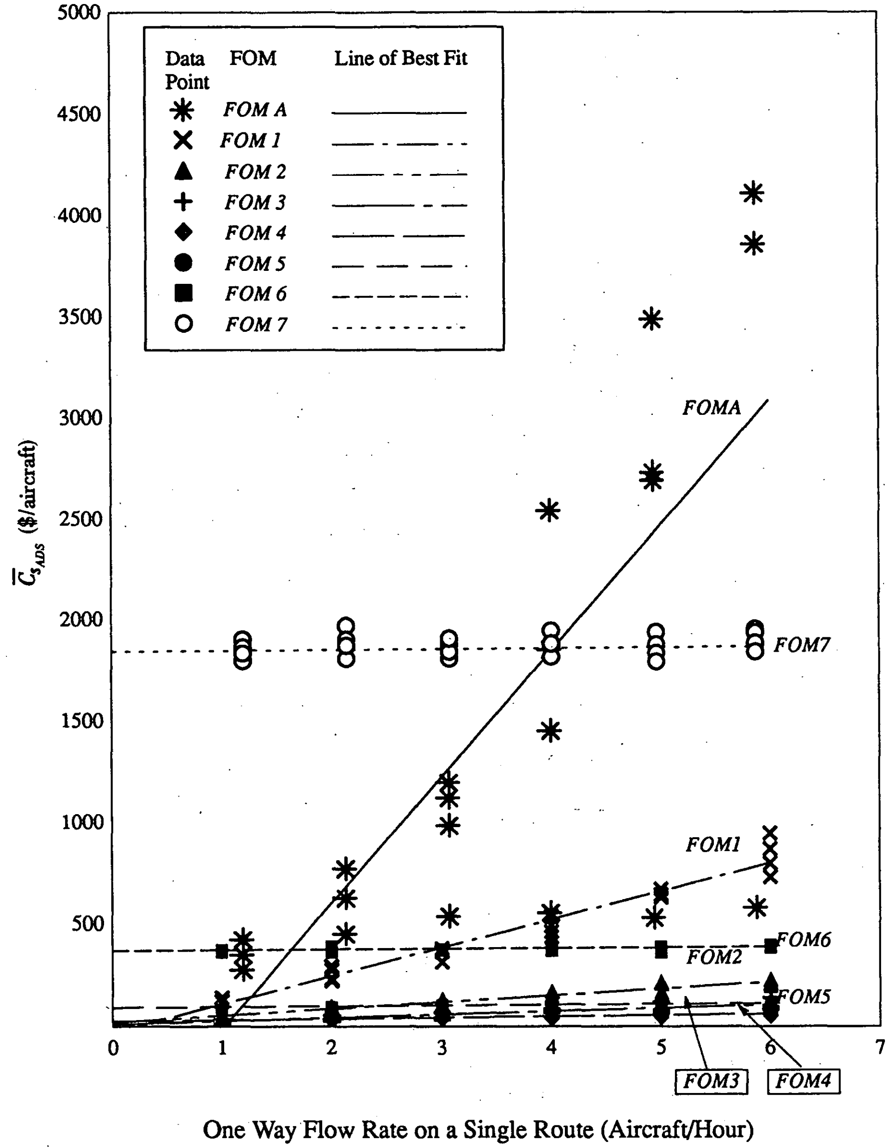


FIGURE 6 Aircraft costings drawn from different levels of flow.

It is possible to investigate the cost-effectiveness of different operating regimes under different flow rates by transposing the data from Figure 6 so that the horizontal axis represents FOM. This transposition is presented in Figure 7. The inset in Figure 7 provides a magnified view of the behavior of the cost function in the minimum cost region.

Figure 7 indicates that the optimum FOM lies between FOM 3 and FOM 4 for flow rates of one to six aircraft per hour per route per direction under the system parameters used in this study. As the flow increases, FOM 4 becomes more attractive when one is minimizing overall costs. It may be possible to yield the minimum cost at higher levels of FOM, such as FOM 5, for much higher flow rates than considered here. Currently, however, such high flow rates are deemed unrealistic.

CONCLUSIONS

The relationship between update rate and minimum separation is examined in this paper. There is, however, a current notion that ADS reports are required only for a change in flight plan. If this is the case, then separation is based solely on FOM. The authors will explore this position in future research.

Regardless of the outcome from the ADS panel, the paper does present a methodology for investigating the effects of technological advances in the field of ATC. During this research project, emphasis was placed on investigating the trend and the nature of the cost functions. It has been shown in a cost comparison between the current state, FOM A, and FOM 3 that the cost savings per aircraft are substantial, even for relatively low flow rates of about one aircraft per hour per route per direction. Annual cost savings would provide significant benefits to the civil aviation industry as a whole. Additionally, including other airports, and therefore increasing the number of routes, in the analyzed region is likely to yield proportional cost savings across the entire network. This result is due to the greater number of intersection nodes created by added routes and the higher number of resolution maneuvers generated by increased crossing conflicts. For future research, a need to further define the relationship between the network complexity and system cost has been identified.

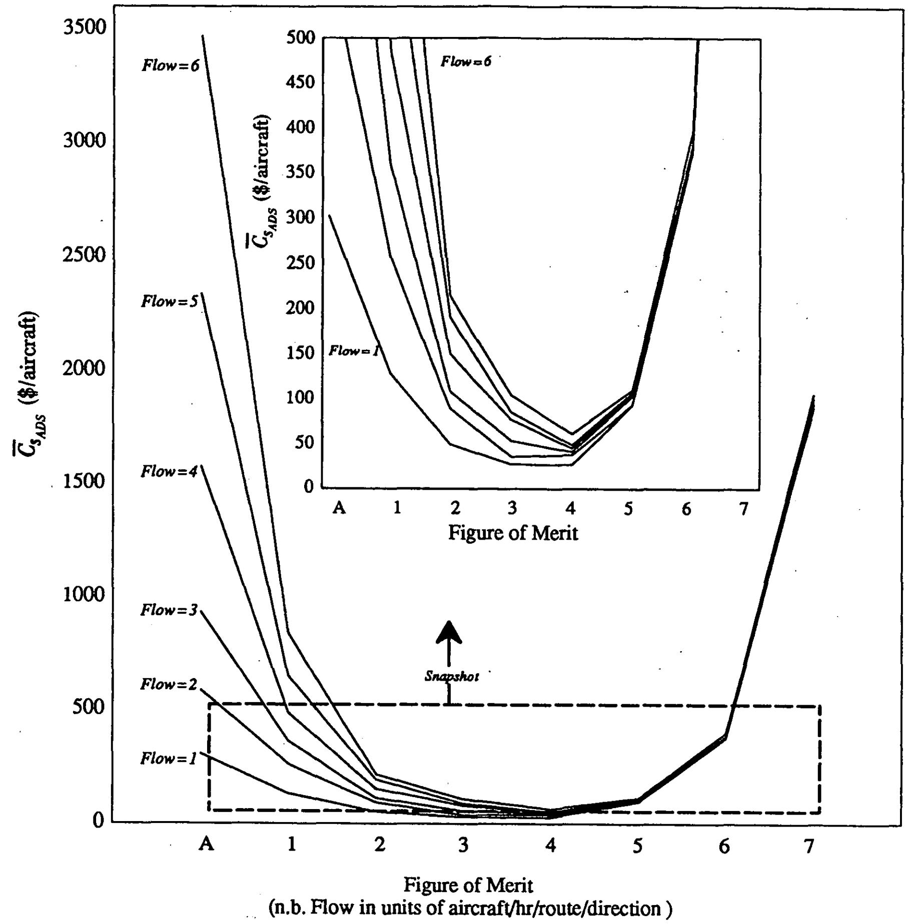


FIGURE 7 Aircraft costings drawn from different levels of flow.

Although the costs of infrastructure and equipment have not been considered in the cost equation, the overall effect of such features is likely to be negligible because of compensatory cost savings expected to be gained from not having to maintain the current land-based navigational aids as well as maintain and renew some costly INS.

The described methodology has allowed for an optimum FOM to be determined as a function of flow rate. As demonstrated, FOMs 3 and 4 provide the optimum operating regime for the given range of flow rates. However, if a superior FOM is desired for safety or policy reasons, a lower update rate to ensure satisfactory cost-effectiveness will be necessary. The potential to reduce the update rate for superior FOMs through considering the low flow rates involved will be limited, however. This limitation reflects real operational behavior in which, although the average flow rate may be low, aircraft tend to operate in bunches and therefore operate close to minimum allowable headways. High update rates therefore will need to be maintained to ensure that separation is properly maintained, thus ensuring that update rates are more closely related to separation minima than flow characteristics.

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Peak Pricing As It Might Apply to Boston-Logan International Airport

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Delay, a chronic problem at many airports, results from an imbalance between airfield capacity and demand. This problem traditionally is addressed through efforts to increase physical capacity. Market-based approaches have been discussed but not yet implemented in the United States. Ways in which peak-period pricing might apply to Boston-Logan International Airport and in which it might affect delay are demonstrated through five steps. First, peak period is identified through analysis of hourly demand and delay data. Second, a cost allocation system dividing airfield costs into three categories—operations, weight, and capacity—is developed. Third, an air service model to predict flights and markets affected by fee changes is generated. Fourth, the expected delay reduction is projected, and fifth, cost savings for airlines and passengers are forecast. Results defined the peak period for delay and congestion to be 2:00 p.m. to 8:00 p.m. weekdays. The cost-allocation method produced a capacity fee just under $100 during the peak period. The air service model estimated a 15 percent reduction in peak-hour flights. Reductions were predicted primarily in high-frequency regional markets with competing airlines. No community was expected to lose access to Logan, even during the peak period. Peak-period delay was predicted to be reduced by 10,000 hr annually, resulting in about $13 million in airline savings and $15 million in time savings for passengers.

Airport congestion and its resulting delay have been a chronic problem at many major U.S. and international airports. The prevalence of airport delay became such a high-visibility public issue during the 1980s that the U.S. Department of Transportation (DOT) began requiring airlines to provide "on-time performance" statistics that confirmed the severity of the problem. Even the downturn in the economy and flight activity during the early 1990s did not eliminate the trouble with delay. Furthermore, now that aviation activity levels have begun to rise again, public awareness and impatience with increasing delays can be expected to rise as well.

Delay results from an imbalance between airfield demand and capacity: delays occur when more aircraft are scheduled into an airport than can be accommodated safely within a given period. Because delay is determined largely by these two parameters, increasing physical capacity (i.e., adding runways) and managing demand are two remedies. Attempts to solve the delay problem traditionally have focused on increasing physical capacity, although that frequently is difficult because of environmental, legal, and political impediments. FAA, which has regulatory authority over U.S. airspace, has managed demand at four U.S. airports by imposing fixed hourly operations limits, or "slots," at Kennedy, LaGuardia, O'Hare, and Washington National airports. Although much has been discussed in transportation and economic literature, no purely market-based approach to peak-period pricing has been implemented at U.S. airports. This paper describes an analytical approach to developing a peak-period pricing system for Boston-Logan International Airport. The proposal, however, has not been implemented.

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BOSTON-LOGAN INTERNATIONAL AIRPORT

Boston-Logan International Airport is an example of a facility with frequent unacceptable levels of delay. Although some limited possibilities for increasing physical capacity may exist at Logan, they cannot be implemented immediately and may not be sufficient to reduce congestion to acceptable levels. Thus, "peak-period pricing," a method to reduce delay through differential pricing, has been investigated as a market-based response to Logan's chronic delay.

Physical Characteristics

Logan Airport is located on a peninsula jutting into Boston Harbor in Massachusetts. Surrounded by water and century-old urban neighborhoods the airport's 2,300-acre area has been fixed for decades. Logan has four major runways (ranging from 7,000 to 10,000 ft in length) and a very short commuter runway (2,450 ft). Two of the four runways are parallel but separated by only 1,600 ft, making the runways too close for simultaneous instrument approaches. Several of the major runways cross each other, thus offering flexibility for operations in varying wind conditions but limiting the maximum number of operations that can be handled when they are used in combination.

Airport Services

Despite Logan's small size (Dallas/Forth Worth Airport has 18,000 acres and the new Denver airport has 30,000 acres in comparison), Logan accommodates an unusually high number of both services and operations. Logan provides six major types of aviation services: both international and domestic commercial passenger flights, all-cargo service, commuter flights, charters, and general aviation. Each of these users has different aircraft types, operating patterns, and facility requirements. For example, international passenger services requires a customs and immigrations hall; cargo services needs buildings with both truck and aircraft access; general aviation operations has its own terminal and aircraft apron; and international, domestic, charter, and commuter carriers require multiple passenger terminals, aprons, and gates of different sizes. Although other airports, such as Washington National and LaGuardia, handle comparable passenger volumes for similar land areas, each of these airports is supplemented by one or more large airports for long-haul and international services. By contrast, Logan is the major short- and long-haul airport for the six-state New England region. As a result, the pressure on Logan's facilities is great, especially at certain times during the day.

Whereas most airports serve as either primarily a hub or an origin and destination (O&D) point, Logan is both a domestic and cargo O&D airport as well as an international and commuter hub. As a result of this dual modality, Logan has 40 competitive airlines for just under 500,000 operations annually. Logan has developed, rather uniquely, as a major commuter-hub airport with three competing regional airline systems that are each associated with a code-sharing affiliate. Several smaller code-sharing and independent regional carriers also serve the market.

These highly competitive regional services are unusual. First, there are often as many as four separate airlines, both jet and nonjet, competing in the same regional markets. Second, regional carriers frequently compete with jet carriers, which are their own code-sharing affiliates sometimes, on major city routes not traditionally considered as "regional" markets.

Because of its unusual service pattern, Logan has very high service frequencies, often using small commuter aircraft. More than 60 percent of regional flights at Logan are in aircraft with 19 or fewer seats. Logan also has the highest overall percentage of nonjet aircraft operations at more than 50 percent and the smallest average aircraft size among major U.S. airports. Serving just below 23 million passengers in 1992, Logan ranked 10th among U.S. airports in total passengers but 5th in total aircraft operations. As a result of this combination of factors, Logan ranks fourth in delay nationally.

MEASURING DELAY

Even under ideal conditions, capacity at Logan is often insufficient to meet demand during peak periods. In reality, capacity often is restricted by factors that include the specific runway combination in use, wind and weather conditions, mix of aircraft types, and ratio of arrivals to departures. Depending on the combination of conditions, Logan's capacity ranges from about 40 to 120 operations per hour. Because demand does not vary much with the hourly capacity of the airport, when high demand coincides with periods of less-than-maximum capacity, delay at Logan can be, and historically has been, extremely high.

FAA classifies an airport as congested if it experiences more than 20,000 hr of aircraft delay a year. Although precise delay statistics for the nation's airports are difficult to obtain, there is no doubt that Logan Airport's threshold has been exceeded greatly for a long time. Estimates of aircraft delay at Logan for 1992 are near 100,000 hr a year, or five times the FAA threshold for a congested airport.

The cause for increasing delay at Logan is the constant increase in the number of scheduled airline operations without a comparable growth in the number of passengers. Logan's passenger volume dropped at the beginning of this decade, and, although now returning to previous levels, passenger volume has not yet reached the historic 1988 peak of 23.7 million passengers (Figure 1).

Growing numbers of operations and a declining or unchanging or flat volume of passengers indicates fewer passengers per aircraft operation. Indeed, Logan today ranks at the bottom of the world's 25 busiest airports in passenger volume per aircraft operation with an average aircraft size of 85 seats per operation. Figure 2 demonstrates the source of the increase in operations and decrease in average aircraft size. Whereas jet operations have increased by only 9 percent since 1986, nonjet operations have increased by more than 75 percent. Figure 3 indicates that Boston is the busiest commuter airport in the country and had the highest overall percentage of scheduled regional carrier flights (as a share of total scheduled departures), 54 percent, in August 1993. Figure 4 shows the growth in regional airline activity at Logan; data include only nonjet aircraft.

A high volume of operations with relatively few passengers on each operation puts enormous pressure on the airfield, especially during the busiest period of the day. Indeed, comparing Logan with other large airports raises interesting questions about efficiency. Most of these airports enplane between 65 and 135 passengers per flight, whereas Logan enplanes 56 passengers per flight.

Thus, the operational congestion and delay at Logan are driven not only by total passenger demand but also by a combination of factors, including the fleet that serves the airport. Furthermore, because delay is very sensitive to changes in demand when an airport is congested, reducing operations by even a relatively small number during the most congested period may reduce delay at Logan significantly. Reducing the number of peak-period operations could, in fact, allow Logan's total passenger volume to increase without additional delay, resulting in accommodating both current and future demand.

DEFINING PEAK PERIOD

The first step in developing a peak-period pricing method is to determine when congestion can be expected to be most intense. For Logan, hourly demand profiles were obtained for weekdays, Saturdays, and Sundays, and a delay estimation model was created using a combination of analytic techniques and simulation. Figure 5 shows the profile for average weekday demand for FY 1993 at Logan Airport. Although demand is high during both the morning and late afternoon/early evening, the duration of these peaks differs. Duration is important because the presence of high demand during a single hour is not sufficient by itself to cause serious delay. If an hour of high demand is preceded and followed by hours of low demand, severe congestion may not occur. On the basis of queuing theory, it is reasonable to define a peak period as one that has at least three contiguous hours of high demand. Similarly, practical experience indicates that it would make little sense to declare a "peak period" for pricing purposes of 2 hr or less. Users could then simply make minor schedule adjustments to avoid the peak period, which would have little effect on airfield congestion.

At a congested airport, a reasonable criterion for considering an hour of airfield activity to be in the peak period is that the number of operations demanded during that hour exceeds the average airfield activity for the day by 20 percent or more. This peak-period hour occurs when congestion and delay can be expected to be at their worst. Drawing from the reasoning of the preceding paragraphs, the following criterion reasonably defines peak period at Logan Airport for rate-setting purposes: a peak period will consist of a group of 3 or more contiguous hr; within this group any set of

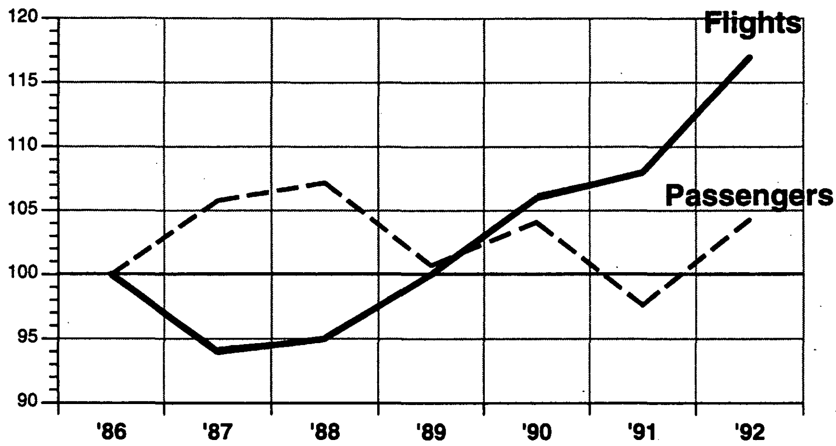

FIGURE 1 Growth in scheduled airline activity at Logan Airport by annual passengers and yearly August schedules (*sources*: *Aviation Department, Massachusetts Port Authority and* ABC World Airways Guide, *Reed Travel Group*).

3 contiguous hr will have a typical demand whose average (during the 3 hr) is at least 20 percent above the average for the day.

Congestion at Logan is heaviest during weekdays. The average number of weekday operations per hour during the 18-hr period from 6:00 a.m. to 11:59 p.m. is approximately 86, ranging from a low of 19 operations between 11:00 and 11:59 p.m. to a high of 115 between 5:00 and 5:59 p.m. Applying the preceding criterion yields a peak-period threshold of about 103 operations per hour. With a threshold of 103 hourly operations, the peak period at Logan would become the period from 2:00 to 7:59 p.m. on weekdays.

Figure 6 uses the maximum 3-hr average demand for each hour to illustrate the weekday profile at Logan. The figure also presents the distribution of total delay throughout the day from a simulation of the FY 1993 Logan demand with 10 years (1981–1990) of actual weather observations at the airfield. The figure clearly illustrates the significant increase in both demand and delays during the afternoon.

The peak period defined using this method is consistent with the current pattern of delays at Logan as reported by DOT. Figure 7 shows DOT on-time (i.e., arrivals/departures within 15 min of scheduled flight time) performance data for Logan by time of day as well as for the combined total of the top 29 U.S. airports (data for midmonth of each quarter, 1992). Both arrival and departure performances deteriorate beginning at about 2:00 p.m. These poor performances occurred despite an average 10-min increase in published flight times that the airlines have allowed during the past decade to account for expected delays at Logan. Although these statistics include effects external to Logan, they clearly confirm the existence of an afternoon/evening peak period at Boston. Therefore, the proposed peak period at Logan Airport would be from 2:00 to 7:59 p.m. on weekdays.

DEVELOPING A COST-ALLOCATION SYSTEM

The peak period having been established, the next analytical step was to articulate a structure for a time-differentiated rate for the peak period.

New Landing-Fee Structure

U.S. airports traditionally have charged landing fees based solely on weight—a fixed charge per 1,000 lb, sometimes with a minimum charge. This "weight only" charge fails to reflect two additional

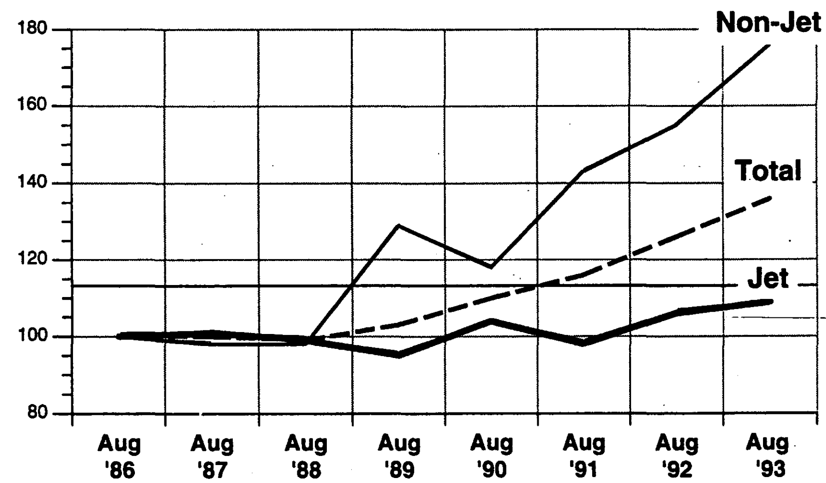

FIGURE 2 Growth in scheduled operations at Logan Airport (*source*: ABC World Airways Guide, *Reed Travel Group*).

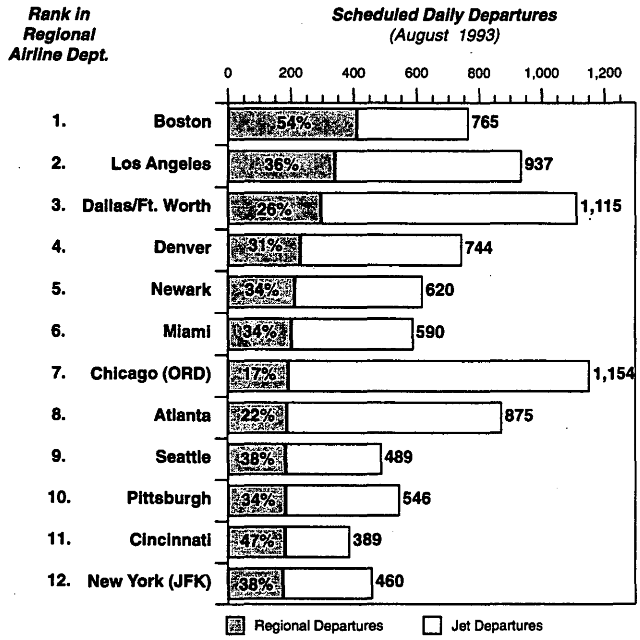

FIGURE 3 Comparison of regional airline departures among major U.S. airports, August schedules (1993 based on July advance schedules) (*source*: ABC World Airways Guide, *Reed Travel Group*).

dimensions of airport costs: first, some costs are "operations related"; that is, they are incurred for each operation, independent of the plane's weight, and second, certain operations-related costs are time dependent. Recognition of these factors produced a landing-fee structure that encompassed three components: a weight-based fee (per 1,000 lb), an operations fee (per landing, independent of weight), and a time-dependent operations or capacity fee, charged only during peak hours.

The three-part rate structure, drawn from different types of airfield costs, creates two incentives: the operations fee encourages carriers to choose larger aircraft because the same operations charge applies to all sizes, and the time-dependent peak-period fee encourages carriers to schedule operations outside of peak periods. Both incentives will reduce delay, first by reducing the total number of operations and then by further reducing the number of peak-period operations.

Whereas airport rate makers have not implemented similar pricing methods in the past, they can follow abundant precedents for them in utility rates. The electric utility industry is one that has an established history of variable pricing by time of day for managing peak demand. Not only do these utility rates recover costs, but the rates also send a signal to users about how their activities affect costs. The demand for services, which is influenced by the prices charged, affects the costs that the utility must incur to provide the desired services, thus affecting total costs. Regulators have encouraged innovative utility rate structures (e.g., time-differentiated pricing) that reflect the effect of peak-period use on a utility's costs.

Utility cost analyses, therefore, provide a useful model for setting cost-recovery airport rates. Whereas peak-period pricing allocates an airfield's costs differently than the traditional weight-based method, both are designed only to recover the costs of the airfield. The choice between methods, therefore, is unaffected by revenue.

Cost-Allocation Method

After establishing the three cost categories—weight, operations, and capacity—each airfield cost item can be assigned (in whole or in part) to these categories according to functional or causal relationships. The steps of this method, as applied to Logan Airport, follow.

To develop a rate structure that reflects cost relationships, it is necessary to identify qualitatively the main factors that drive a facility's costs. Next, the specific costs associated with each factor must be measured quantitatively. Finally, cost differences between classes of users (jets and nonjets) should be recognized. Thus, a three-step procedure commonly used in utility cost-analysis was followed: functionalization, classification, and allocation.

Functionalization

Functionalization is the process of identifying distinct functions of the airfield and grouping together the costs related to each function.

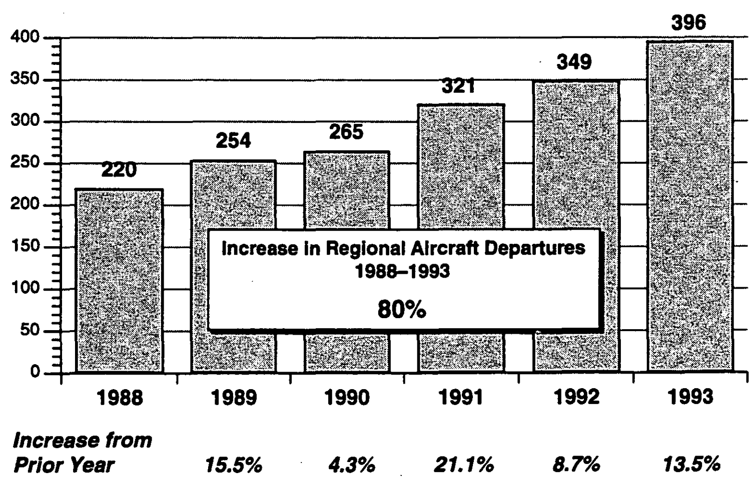

FIGURE 4 Recent increases in regional aircraft departures at Logan, August schedules (1993 based on July advance schedules).

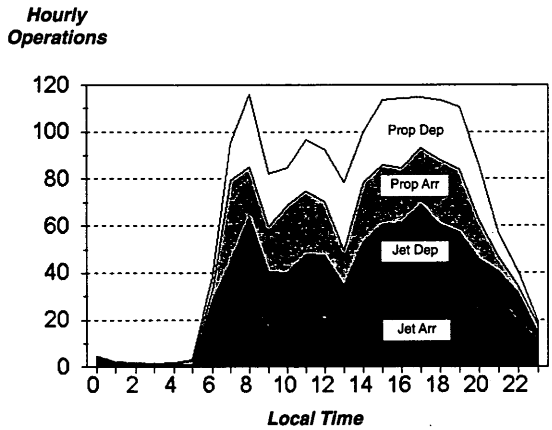

FIGURE 5 Average weekday demand, Logan Airport, FY 1993.

The main functional categories used in this analysis were (a) runways and taxiways, (b) aprons and ramps, (c) navaids and air traffic control support facilities, (d) general airfield costs, and (e) overhead. All airfield costs were functionalized into these five categories.

Classification

Classification is the process of analyzing causal relationships to determine which usage factors affect each functional category of costs. Each cost (or group of costs) was classified into three categories reflecting the main usage factors responsible for airfield costs: peak demand (i.e., aircraft operations during peak period), total aircraft operations, and aircraft weight. In many cases costs were divided among two or three usage categories rather than classified exclusively by one aspect of usage.

- *Capacity-related* costs are incurred to provide and maintain airfield capacity so as to manage peak demand. Capacity-related costs are considered to be attributable to and recoverable from facility users during peak periods.

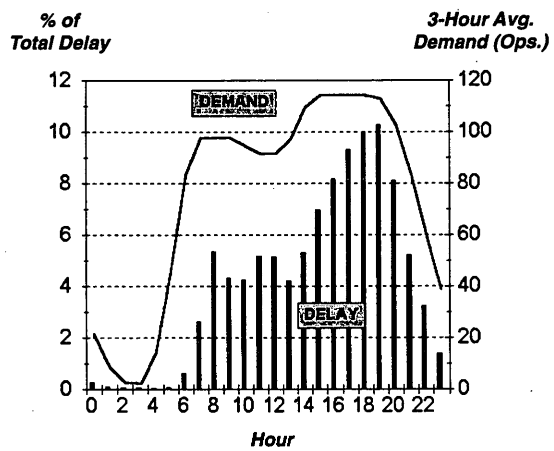

FIGURE 6 Average demand and simulated delays, Logan Airport.

- *Operations-related* costs are incurred for each operation regardless of the time when the operation takes place or the weight of the aircraft. Thus, these costs are the same for peak and off-peak users but are not, however, always the same for jet and nonjet users.
- *Weight-related* costs vary with the weight or size of the aircraft.

Allocation

The final step in cost disaggregation is allocation, which separates users into two or more groups and assigns costs appropriately. This step recognizes qualitative differences among users according to how they affect a particular category of costs. Table 1 demonstrates how costs are assigned by this method.

The allocation process recognizes differences between jets and nonjets, such as by the levels of noise and air pollution they create.

Application to Logan

Applying this cost-allocation method to Logan Airport required disaggregating the total airfield costs according to the three-step system. Table 2 presents the effect of analyzing Logan's Airport FY 1993 airfield budget according to the cost-allocation method.

Table 3 indicates the changes that would result from applying these fees to different-sized aircraft operating at Logan. All aircraft operators would be charged the basic fee (i.e., for operations and weight) whenever they arrived at Logan. During peak hours a separate charge would be added for both landings and departures, a reflection of the time-dependent nature of capacity-related costs. Aircraft with slightly more than 100 seats would pay about the same average cost per operation as they do under the weight-based system. On average, smaller aircraft would pay more and larger aircraft would pay less than they do now. Larger aircraft, however, would always pay higher total fees than smaller aircraft.

AIR SERVICE IMPLICATIONS OF PEAK-PERIOD FEES

Developing Peak-Period Air Service Model

With the ultimate goal of delay reduction in mind, the next important analytical step in developing a peak-period pricing method is to assess air service implications from several perspectives. For example, how many flights would be affected during the peak period? Which markets and airlines likely would be affected? Would fares be expected to increase, and, if so, in which markets? Would smaller communities that rely on regional airlines for service to Logan be significantly affected by either service reductions or fare increases? What effects would service changes have on expected levels of delay, and what cost savings would be expected for airlines and passengers as a result of the predicted delay reduction?

To address these questions, an analytic model was developed for estimating the effect on profitability for each regional airline by market. The model also predicts, by carrier and market, the probability of flight cancellations or rescheduling to avoid peak-hour fees. A schematic of the model appears as Figure 8.

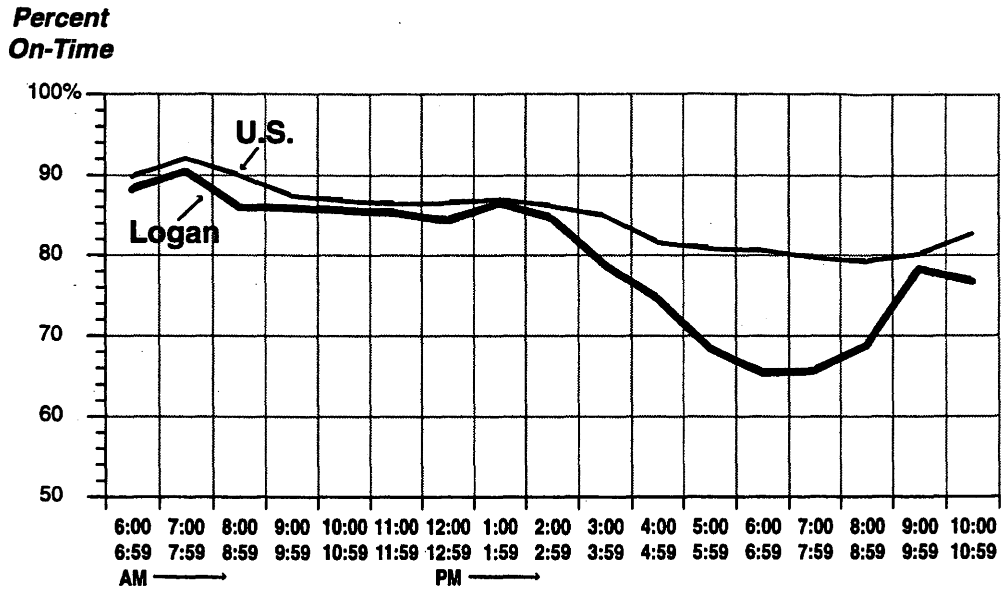

FIGURE 7 On-time performance at Logan Airport versus U.S. average for major airports.

Description of Model and Underlying Assumptions

The first step of the model is to estimate the change in carriers' costs of providing service according to actual schedules (i.e., summer and winter) in each market, assuming peak-period pricing is in effect.

As a rule, all major jet carriers would have cost savings in all markets. There would be savings because these carriers operate aircraft of 100 or more seats on average, which means lower fees according to the average Logan distribution of 35 percent peak and 65 percent off-peak operations. However, the magnitude of cost savings, even for the largest widebody aircraft, would be less than $1.00/passenger and would not be sufficient to induce either more flights or lower fares. Therefore, the peak-hour pricing fees are expected to have no material effect on the flight schedules of jet airlines at Logan.

TABLE 1 Illustrative Airfield Cost-Allocation Methodology for Logan Airport (millions)

Function Classification	Total	User Group Allocation Jets	Non-Jets
Runways & Taxiways			
Capacity	$29.3	$18.4	$10.9
Operations	11.0	6.3	4.7
Weight	17.5	16.2	1.3
Total	57.8	40.9	16.9
Aprons & Ramps			
Capacity	0.0	0.0	0.0
Operations	0.0	0.0	0.0
Weight	22.8	21.1	1.7
Total	22.8	21.1	1.7
Navaids			
.	.	.	.
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Note: These figures are net investments.

Regional airline flights, on the other hand, would experience higher average costs on virtually all routes. The model assumes that regional airlines would, if possible, pass these higher costs on to passengers as fare increases, as is the case with other costs of operations, such as higher fuel prices. In some market situations, however, competitive forces will prevent carriers from increasing their fares. For example, a regional airline operating a 19-seat aircraft, which may require it to charge a $10 fare increase (accounting for the price elasticity of passengers) to maintain the same profit in a market, would not be able to increase its fares if it were competing with a jet carrier that would not need to increase its fares or with another regional carrier that required only a $5 fare increase to operate a 50-seat aircraft.

Therefore, the model assumes that in any given market a carrier could increase fares only to the extent of the least affected competitive carrier in the market. When regional aircraft are competing with jet service, no fare increase is assumed. Cost increases that cannot be offset by fare increases because of competitive circumstances are assumed to be absorbed by the carrier as reduced profitability.

The effect on profitability model considers, to the extent possible, the specific economic characteristics of each regional carrier route, including the mix of local and connecting traffic, average fares and prorations of fares for connecting traffic, and the type of aircraft and time of day of the flights. In estimating the effect on traffic due to a fare increase, a −0.7 price elasticity was assumed. This price elasticity means that the required fare increase due to higher airfield user fees will exceed the amount of the cost increase, since some passengers will not travel at the higher fare level.

The model then estimates the probability of peak-period flight cancellations according to the percentage reduction in the profit margin for each carrier market. For example, with a profit reduction of 2.5 to 5.0 percent, 30 percent of a carrier's peak-period flights are assumed to be canceled. The cancellation rate rises to 50 percent, with a 5.0 to 7.5 percent reduction in profit margin, and to 75 percent if the profit margin is reduced by more than 10.0 percent.

TABLE 2 Logan Airport Airfield User Charges, Existing and Illustrative Rates, Using Peak-Period Pricing

Existing Rates	
Weight Charge	$1.69 per 1,000 lbs. (landed weight) (with a minimum $25 landing fee)
Illustrative Rates	
Weight Charge	$.55 per 1,000 lbs. (per landing, all aircraft types)
Operations Charge	$56.09 per jet landing $40.58 per nonjet landing
Peak-Period Charge	$99.94 per landing and per takeoff in the peak period

The peak period is defined as 2:00 p.m. to 7:59 p.m., Monday through Friday.

Expected Changes in Peak-Period Service

The model predicts that if this peak-period pricing method were introduced at Logan, a total of 111 weekday operations would be expected to be moved out of the peak period. This peak-period reduction represents a reduction of approximately 30 percent of regional airline flights and about 15 percent of total scheduled air-carrier operations during the weekday peak, according to July 1993 schedules. The model estimates that 72 of the flights would be canceled (or an average of 12 operations per peak hour) and that 39 flights would be rescheduled off-peak. Most of these rescheduled flights are within 30 min of the beginning or end of the peak period.

TABLE 3 Comparison of Existing and Illustrative Airfield User Fees Using Peak-Period Pricing at Logan Airport for Representative Aircraft Types

		Average Airfield User Fee per Operation		
Aircraft Type	Average Seats	Existing[1]	Peak Pricing Method[2]	Increase (Decrease)
B-747	400	$493.48	$223.62	$(269.86)
B-757	190	167.31	117.47	(49.84)
B-727	150	129.29	105.10	(24.19)
B-737	108	92.11	93.00	.89
ATR-42	47	29.58	64.89	35.32
Metro	19	12.50	59.12	46.62

[1]Existing landing fee divided by 2 for average fee per operation.
[2]Weighted average fee assuming 65% off-peak and 35% peak operations.

The model estimates that the vast majority of flight cancellations are in markets that currently have exceptionally high flight frequencies. (Table 4 presents a summary of the predicted service and fare changes in each of the 49 nonstop markets served by regional airlines from Logan.) For example, more than half of the flight cancellations are predicted to be in five markets: Portland (Oregon), Bangor (Maine), New York (Kennedy Airport), Newark (New Jersey), and Philadelphia (Pennsylvania). Each of these markets currently has a minimum of 29 daily roundtrip flights; each market is served by three or more airlines and enjoys nonstop jet service. Clearly, the expected service reductions will not greatly reduce passenger travel options in these high-frequency markets, and frequent service will continue to be provided during the peak period.

With few exceptions, all other predicted flight cancellations are in well-served markets with 10 or more daily roundtrips. Some of these markets also have nonstop jet service. No community would be expected to lose access to Logan because of this peak-period pricing method.

Smaller communities and markets with monopoly service by regional airlines would be expected to have fare increases rather than service reductions. In fact, more than half of the 49 regional carrier markets served from Boston are not expected to lose any flights but may have fare increases near $5 to $15. In most of these markets, this increase would be less than a 10 percent increase in fares.

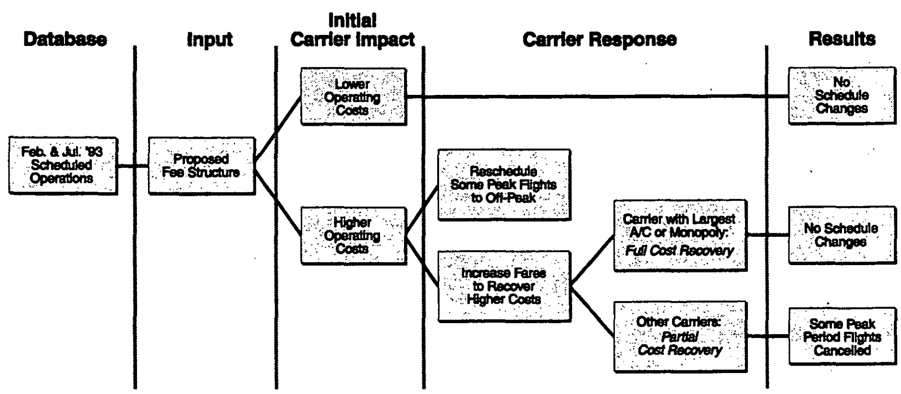

FIGURE 8 Model for estimating impact of revised fee structure.

TABLE 4 Summary of Predicted Service and Fare Effects by Market at Logan Airport with Peak-Period Airfield User Fees, July 1993

Rank	Market	Weekday Flights (All Day) \1	Peak Period Weekday Flights Canceled		Weekday Seats (All Day) \1	Peak Period Weekday Seats Canceled		Fare Increase	
			Number	Percent		Number	Percent	Net	Percent
1	Newark *	76	4	6%	7,730	79	1%	$0.00	0%
2	Portland *	68	15	21%	2,585	355	14%	$0.00	0%
3	New York (JFK) *	64	6	9%	3,677	240	7%	$0.00	0%
4	Philadelphia *	60	3	6%	4,835	98	2%	$0.00	0%
5	Washington National *	59	1	1%	6,666	25	0%	$0.00	0%
6	Bangor *	58	9	15%	2,455	225	9%	$0.00	0%
7	Manchester	44	4	8%	954	71	7%	$4.64	3%
8	Islip	43	2	6%	1,055	46	4%	$8.53	7%
9	Burlington, VT	41	3	8%	1,007	60	6%	$5.10	4%
10	Baltimore *	34	2	5%	2,713	68	3%	$0.00	0%
11	White Plains	34	1	3%	932	19	2%	$7.79	7%
12	Martha's Vineyard	33	4	13%	497	47	9%	$4.99	4%
13	Lebanon	32	3	8%	608	48	8%	$5.79	4%
14	Hyannis	31	4	11%	776	67	9%	$2.72	2%
15	Nantucket	31	3	11%	640	66	10%	$5.22	4%
16	Albany	29	1	2%	551	12	2%	$15.03	14%
17	Washington Dulles *	25	1	2%	2,908	21	1%	$0.00	0%
18	Syracuse *	22	2	9%	1,126	45	4%	$0.00	0%
19	Rochester *	20	1	6%	1,324	34	3%	$0.00	0%
20	Hartford	18	2	9%	467	32	7%	$4.14	3%
21	Buffalo *	15	0	2%	1,120	10	1%	$0.00	0%
22	Montreal *	14	1	7%	1,585	35	2%	$0.00	0%
23	Ottawa, OT	14	0	0%	462	0	0%	$5.40	4%
24	Presque Isle	13	0	1%	311	2	1%	$5.10	3%
25	Portsmouth	12	0	0%	412	0	0%	$2.19	1%
26	Providence	11	1	9%	233	18	8%	$4.95	3%
27	Provincetown	11	0	0%	99	0	0%	$16.02	12%
28	Rockland, ME	10	0	0%	158	0	0%	$8.81	6%
29	Quebec, QU	10	0	0%	190	0	0%	$11.99	8%
30	Saint John, NB	9	0	1%	238	2	1%	$7.30	4%
31	Harrisburg	8	0	0%	296	0	0%	$7.15	5%
32	Bridgeport	8	0	0%	152	0	0%	$10.51	7%
33	Bar Harbor	8	0	0%	152	0	0%	$12.18	11%
34	Farmingdale, NY	8	0	0%	152	0	0%	$11.39	10%
35	Moncton, NB	8	0	0%	220	0	0%	$8.98	4%
36	Augusta	8	0	0%	152	0	0%	$6.81	5%
37	Richmond *	7	0	2%	571	12	2%	$0.00	0%
38	Binghamton	6	0	0%	114	0	0%	$12.06	8%
39	Atlantic City	6	0	0%	108	0	0%	$16.84	17%
40	Newburgh	6	0	0%	156	0	0%	$7.85	5%
41	Allentown	6	0	0%	186	0	0%	$6.22	5%
42	Norfolk *	5	0	2%	446	8	2%	$0.00	0%
43	Rutland	5	0	0%	75	0	0%	$11.90	9%
44	Wilkes-Barre	4	0	0%	76	0	0%	$16.94	13%
45	Ithaca	4	0	0%	76	0	0%	$15.54	13%
46	Yarmouth, NS	4	0	0%	148	0	0%	$0.33	0%
47	Laconia	4	0	0%	60	0	0%	$6.29	5%
48	Fredericton, NB	3	0	0%	54	0	0%	$15.51	9%
49	Keene	1	0	0%	15	0	0%	$16.86	12%
	Total	1,050	72	7%	51,523	1,743	3%	$1.66	1% \2

Note: Ranked by total weekday flights.
* Indicates a market with jet carrier service

\1 Includes regional and jet carriers.
\2 Weighted average based on seat distribution.

Effect on Carriers

Three major code-sharing regional airline systems (Delta, Northwest, and USAir) account for 85 percent of the total scheduled regional airline operations at Logan. These three carrier systems would also be the most affected by the predicted flight cancellations, accounting for about 90 percent of the expected canceled flights. Among these large regional carriers, the most affected operates the highest number of 19-seat aircraft, often in competition with larger turboprop and jet aircraft. Therefore, although these three major regional airline systems would be affected, they and their code-sharing jet partners (and their passengers) also would be among the primary beneficiaries of the reduced congestion and delays at Logan.

DELAY SAVINGS

In bringing the analysis full circle, the next step was to determine what the delay savings for Logan Airport would be if these peak-period service reductions took place. Feeding the predicted cancellations and flight shifts back into the delay estimation model yields the prediction that service changes of this magnitude likely would reduce delay at Logan by a minimum of 10,000 hr annually during peak periods.

All airlines operating at Logan, including the regional carriers, would experience significant cost savings from delay reductions of this magnitude. Assuming standard operating costs for each aircraft type, including fuel and wages, airlines at Logan would be expected to save $13 million annually, whereas their passengers would save about $15 million in lost time.

CONCLUSIONS

The potential benefits of airport delay reduction, airline cost savings, and passenger convenience resulting from peak-period pricing at Logan Airport are substantial. However, for these benefits to be realized at Logan, or at any other airport, certain circumstances must be present. First, real, measurable congestion must occur regularly. Second, the airport must not be subject to FAA slots or any other external regulatory scheme that would reduce the effect of market forces. Third, because the proposed method targets only cost recovery and not netting profits for the airport's operator, there is a limited differential between peak and off-peak fees. Therefore, the peak-period fleet mix must be sensitive to relatively small fee changes. Finally, an airport ideally would have a sufficient quantity of air service to affected markets so that the reductions in peak-period operations would not eliminate access to a particular community. With these criteria in mind, a peak-hour pricing program would offer immediate and tangible benefits for airports plagued by congestion and delay.

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Criteria for Evaluating Quality of Service in Air Terminals

PRIANKA N. SENEVIRATNE AND NATHALIE MARTEL

A set of indexes for evaluating the quality of service in air terminals is presented. It is assumed that quality is comfort and convenience as perceived by users, and a set of indexes that makes evaluation simple and fast is proposed. These indexes represent several terminal characteristics (e.g., walking distance, accessibility, availability of seats, and orientation) identified by passengers during an attitudinal survey at Montreal International Airport at Dorval, Quebec, as well as the conventional level-of-service measures such as density and delays. Six intervals are defined for each index, and each interval represents a specific level of service offered to users. These indexes may be used easily to evaluate the quality of service in other multimodal terminals.

Although airport managers have been using efficiency measures for many years to monitor financial and economic performance of passenger terminals, there are no standardized procedures or universally accepted criteria for evaluating terminal quality of service in relation to user expectations. Even the standard manuals and texts on airport engineering that have emphasized the need to pay attention to social, environmental, and political concerns have not referred to the user needs other than broadly. For example, Ashford et al. (*1*) state only two planning objectives that relate directly to passenger terminals: to provide luxurious facilities in waiting areas and to provide a wide range of commercial activities in the terminal. Apart from such vague descriptions, there is limited information on what constitutes an acceptable level of service or good performance in the eyes of the users. There is also uncertainty about the significance and measurement or quantification of performance measures.

This paper presents a conceptual framework for evaluating the quality of service in air terminals, focuses on performance in relation to the serviceability of terminal subsystems as perceived by users, and proposes a set of indicators that makes evaluation simple, flexible, and quick. These indexes represent several terminal characteristics (e.g., walking distance, accessibility, availability of seats, and orientation) identified by passengers during an attitudinal survey at Montreal International Airport at Dorval, Quebec, as well as the conventional level-of-service measures such as density and delays. Six intervals are defined for each index, and each interval describes the level of service offered to users. Terminal performance in relation to any characteristic then can be rated according to these levels of service.

PERFORMANCE INDICATORS

Almost two decades ago, the participants at a TRB workshop (*2*) examined terminal performance indicators comprehensively. They identified more than 25 qualitative and quantitative characteristics relevant to 12 terminal subsystems or components. More recently, the International Foundation of Airline Passengers' Associations conducted a survey of 30,000 passengers (*3*). Most of those passengers indicated that time spent at check-in and baggage claim is the single most important characteristic that they look for in an airport. Seneviratne and Martel (*4*) performed a survey of departing passengers at the Montreal Airport in Dorval, Canada, to determine their perceptions of a subset of characteristics identified by Heathington and Jones (*2*). One of the key findings of this study was that each subsystem has a particular characteristic that is considerably more important to the majority of the passengers than other characteristics are. For instance, most respondents indicated that the availability of information and signs is the single most important characteristic in circulation subsystems but emphasized that waiting time is the most significant in processing subsystems.

From this point of view, the capacity analysis framework suggested by the Airport Associations Coordinating Council/International Air Transport Association (AACC)/(IATA) (*5*), which considers density to be the critical performance indicator (PI) regardless of the subsystem, has two major deficiencies: first, density is more of an efficiency measure than a characteristic that truly reflects user perceptions, and second, the six-level scheme used to rate each terminal subsystem performance is dated and rigid. The framework is not geared for assessing the influence of different characteristics of passenger streams (e.g., baggage carrying versus cart pushing or different ratios of moving passengers to stationary passengers) on capacity. The only recognizable change in density-based PIs during the past 15 years has been in the intervals assigned to the different levels of service and in the treatment of subsystems. In other words, AACC/IATA recommends more space per person at each level of service (*5*) than does IATA in its 1976 manual (*6*); also space standards for check-in areas differ from those for waiting areas, baggage claim areas, and so forth. The other noteworthy change is that in Europe waiting time has become a standard measure of level of service in processing subsystems.

REPRESENTATIVE INDICATORS

Performance indicators can be designed to reflect either efficiency or effectiveness. Whereas efficiency indicators are important for management to assess the extent to which the system is being used, the effectiveness indicators are what will capture information on the extent to which basic passenger needs are met.

According to Silcock (*7*), the chosen indicators should satisfy the following four criteria:

- Reflect the specific objectives of the management,
- Be simple to define and quantify,
- Not require in-depth and expensive data collection, and

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• Be sensitive to changes due to improvements or managerial actions.

Each subsystem has a different assortment of physical and operational characteristics important to users. Not all characteristics are simple to quantify or define, however, and acceptable standards for them can only be established through in-depth interviews and surveys. Although characteristics, such as density (i.e., level of congestion), currently used to set standards for physical design and to measure service level can satisfy all the foregoing criteria, users do not always view them as important. Thus, the management should have a set of indicators available from which it can select those most suited for its own purposes.

In the present case, six indexes were developed to describe terminal subsystem characteristics, with the first five identified by passengers (*4*) as critical for the general comfort and convenience of the transfer between airside and landside:

- Availability of seats,
- Walking distance,
- Accessibility,
- Orientation (i.e., availability of information),
- Waiting time, and
- Occupancy (i.e., density).

To be consistent with the existing practice, six intervals were defined for each index. These intervals, or levels of service in this case, were derived subjectively, but they can be adjusted easily to suit management needs or changing user perceptions.

Availability of Seats

In the survey reported by Seneviratne and Martel (*4*), 44 percent of the respondents in waiting areas considered availability of seats to be the most significant performance indicator. Thus, the present policy of many airport authorities to provide seats for 50 percent of the occupants in the gatehold areas immediately before departure of the flight seems reasonable. However, if user preferences can be accounted for by willingness to pay as suggested by Wirasinghe and Shehata (*8*), the optimal number of seats (N_o) can be estimated at any given cost for furnishing the seats. Using this estimate, a seating availability index is defined as follows:

$$\mathrm{PI}_{\mathrm{as}} = \frac{N_a}{N_o} \qquad (1)$$

where

N_a = number of available seats in area considered at a given time,
N_o = optimal number of seats, and
$\mathrm{PI}_{\mathrm{as}}$ = performance index for availability of seats.

Thus, level of service (LOS) in relation to availability of seats can be defined as

LOS	PI_{as}
A	≥1.0
B	0.9–0.7
C	0.6–0.4
D	0.3–0.2
E	0.2–0.1
F	<0.1

Walking Distance

Despite their importance, reliable data on passenger walking distances in terminal buildings are not readily available. Thus, it generally is assumed that most passengers walk either from gate to gate if they are transferring passengers or between gates and curbside if they are terminating or originating passengers. These distances generally are measured from the floor plans. In reality, however, because of the positioning of the subsystems (i.e., terminal configuration) and the number of alternative routes connecting most nodes, the walking distance between any two points in a terminal often varies. Thus, the objective should be not only to minimize average walking distance but also to minimize the variance.

In this paper the authors assume that, ideally, all passengers walk the same distance, otherwise the standard deviation of the walking distance distribution in a terminal should be as small as possible. Accordingly, the performance index (PI_w) is defined as a function of the coefficient of variation (CV_w) of walking distance, or the ratio of the standard deviation to the mean. The following index is easy to compute and is sensitive to the standard deviation of walking distance, making it suitable for comparing different terminals or alternative terminal configurations:

$$\mathrm{PI}_w = \frac{1}{1 + CV_w} \qquad (2)$$

LOSs are defined in relation to PI_w:

LOS	PI_w
A	≥1.0
B	0.8–0.9
C	0.6–0.7
D	0.4–0.5
E	0.2–0.3
F	≥0.1

Accessibility

An earlier passenger survey by Seneviratne and Martel (*4*) revealed that accessibility to concessions and services is the second most significant characteristic, or indicator, of performance in waiting areas. The concessions in that study included rest rooms, communication facilities (i.e., phones and facsimile), retail outlets, and restaurants. The following accessibility index is defined on the basis of the additional distance that a passenger has to walk while proceeding from one activity to another:

$$\mathrm{PI}_a = \frac{\sum_{\text{all } i} \sum_{\text{all } j} d_{ij} v_j}{V \sum_{\text{all } i} d_{ik}} \qquad (3)$$

where

PI_a = performance indicator for accessibility,
d_{ij} = walking distance from activity i to concession j,
v_j = number of passengers attracted to concession j in a given time,
d_{ik} = walking distance from activity i to activity k, and
$V = \Sigma v_j$.

This index accounts for the importance of the different concessions by attaching a weight that is relative to the number of passengers attracted to each concession. Because PI_a can take values greater than 1, LOSs are defined in relation to PI_a's inverse. In other words, as PI_a increases, LOS decreases so that $PI_a = 1$ represents perfect accessibility, or LOS A. The ranges that the accessibility index may take at the different levels of service are as follows:

LOS	$1/PI_a$
A	≥0.9
B	0.9–0.7
C	0.6–0.4
D	0.3–0.2
E	0.2–0.1
F	<0.1

To illustrate the estimation and the use of this index, a case study of the domestic wing of the Montreal International Airport at Dorval is presented. The floor plan of the study area is shown in Figure 1. Major activities, such as check-in counters of different airlines, security checks, concessions, and waiting areas, are considered as independent nodes. The distance d_{ik} represents the distance between nodes. In cases in which there are several links between a node pair, the average of all link lengths may be used or, if detailed data are available, all paths could be used in the analysis. This example uses the average length approach. For instance, the distance between the entrance and check-in is taken to be the mean of the distances between all entry points and one central check-in counter.

The number of passengers visiting each concession (v_j) was available from the airport authority. These numbers and the distances estimated from the floor plan, given in Table 1, were used to compute an accessibility index of 1.88 for the departing passengers. This index suggests that the existing terminal configuration and the location of concessions require the average passenger to walk 88 percent more than the passenger who would not visit any concessions. According to the preceding accessibility LOSs, the departure facility at Dorval operates in LOS C (i.e., $1/PI_a = 0.53$).

Orientation

One of the first efforts to quantify passenger terminal building orientation is reported by Braaksma and Cook (*9*). Braaksma and Cook's proposed quantification technique requires the terminal to be represented by a set of nodes and links and each node to be classified into two groups according to whether the other nodes are visible from it. By collating this information into an origin-destination matrix and taking the proportions of visible nodes from each node, an index can be computed for the entire terminal or any given subsystem.

This technique has two drawbacks: first, it does not consider the relation between nodes in connectivity; second, the order in which a passenger proceeds through the nodes is disregarded. In other words, no distinction is made between the primary (or mandatory) nodes (i.e., the nodes that every passenger must pass through) and the secondary (or optional) nodes (i.e., the nodes that one can avoid passing through).

This paper defines an orientation index that overcomes the preceding two deficiencies and describes this index in the following example.

Consider the enplaning process with few concessions shown in Figure 2 and assume the following:

1. The primary activities (nodes) are entry equals 1, check-in equals 2, and security check equals 3.
2. The secondary activities (nodes) are concession equals 4, concession equals 5, and concession equals 6.
3. It is not possible or normally required to return to a primary activity already visited.
4. A passenger cannot or is not normally required to return to the first activity (i.e., entry).
5. Once at the last activity (i.e., security check), a passenger cannot return to the public area.

With these assumptions, the visibility matrix (Figure 3) for the example is defined as

0 = not visible

1 = visible (either directly or indirectly through signs)

— = visibility not required because of the relation between nodes (activities)

Suppose that the matrix can be divided into three parts and two triangles, as follows:

- Part A: upper-left quarter (primary activities versus primary activities),
- Part B: upper-right and lower-left quarters (primary activities versus secondary activities),
- Part C: lower-right quarter (secondary activities versus secondary activities),
- $V_{\text{upper triangle}}$ = sum of entries in each row in upper triangle of matrix, and
- $V_{\text{lower triangle}}$ = sum of entries in each column in lower triangle of matrix.

Global Orientation

The global orientation index (V_g) for the terminal is defined as the ratio of total available sight lines to the required number of sight lines. The parameters needed for estimating this ratio are as follows:

Total number of nodes (N) = $K + J$

where K is the number of primary nodes = 3, and J is the number of secondary nodes = 3.

$$\text{Total observed number of sight lines } (L_o) = \sum V_{\text{lower triangle}} + \sum V_{\text{upper triangle}}$$

$$\text{Required number of sight lines } (L_r) = N(N-1) - [K(K-1) - (K-1)^2] - [2(N-K)] = N^2 - 3N + K - 1 \qquad (4)$$

where

$N(N-1)$ = total number of cells in matrix,
$K(K-1) - (K-1)^2$ = number of cells in which visibility is not required because of order of primary activities, and
$2(N-K)$ = number of cells in which visibility is not required because of Assumptions 4 and 5.

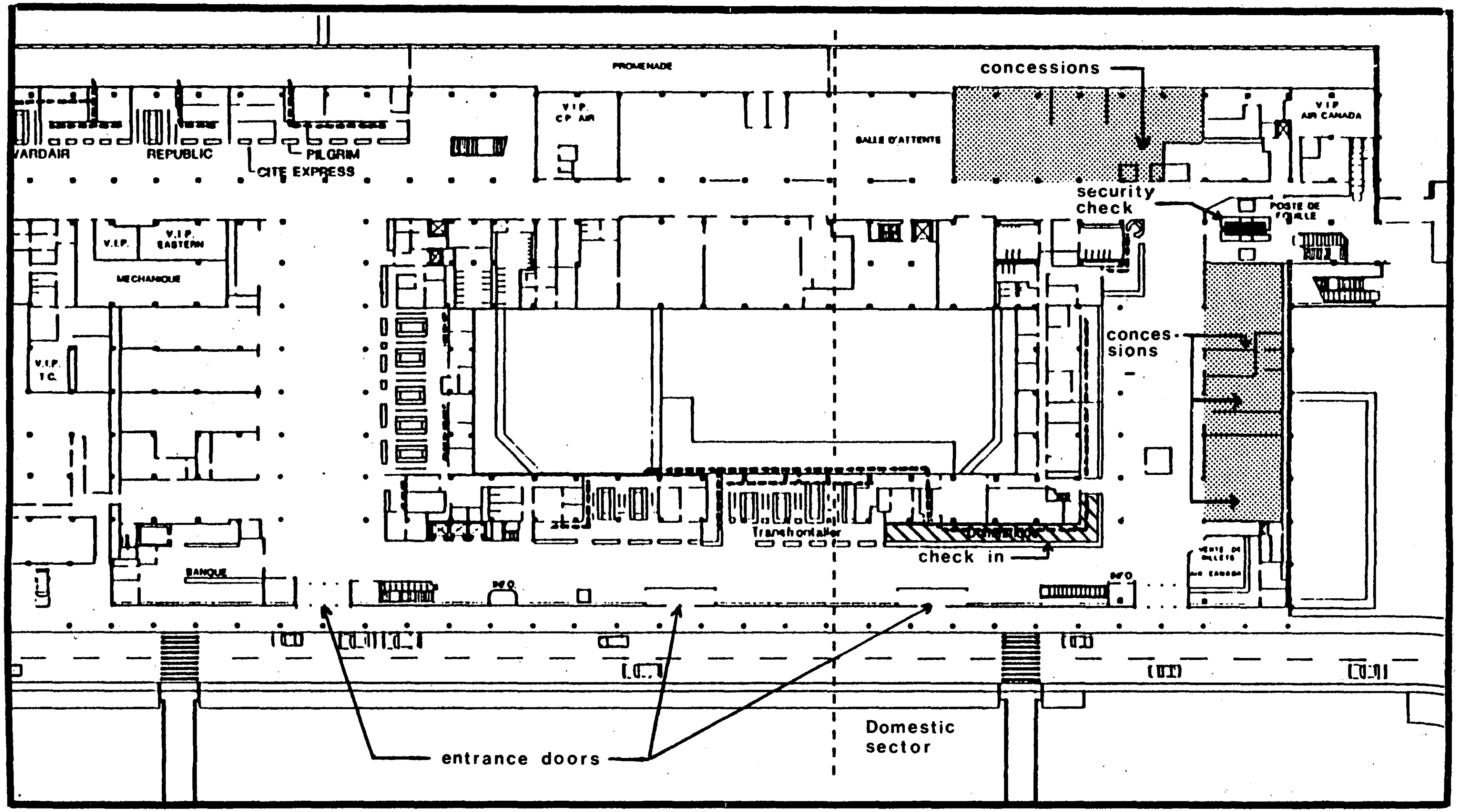

FIGURE 1 Floor plan of Dorval airport.

TABLE 1 **Detailed Calculations for Accessibility Index: Domestic Sector**

Activity 1 - Activity 2	Distance for door 1	Distance for door 2	Distance for door 3	Mean for all doors	Passenger volumes at concessions	Mean * Volumes
Entry-conc.1	130	180	142	151	102	15402
Entry-conc.2	132	80	41	84	25	2100
Entry-conc.3	140	85	47	91	2	182
Entry-conc.4	147	90	52	96	16	1536
Entry-conc.5	154	97	59	103	51	5253
Entry-conc.6	166	105	69	113	29	3277
Entry-conc.7	180	127	90	132	25	3300
Check-in-conc.1	135	135	135	135	102	13770
Check-in-conc.2	34	34	34	34	25	850
Check-in-conc.3	42	42	42	42	2	84
Check-in-conc.4	49	49	49	49	16	784
Check-in-conc.5	56	56	56	56	51	2856
Check-in-conc.6	64	64	64	64	29	1856
Check-in-conc.7	83	83	83	83	25	2075
Security-conc.1	57	57	57	57	102	5814
Security-conc.2	44	44	44	44	25	1600
Security-conc.3	35	35	35	35	2	70
Security-conc.4	30	30	30	30	16	480
Security-conc.5	26	26	26	26	51	1326
Security-conc.6	15	15	15	15	29	435
Security-conc.7	15	15	15	15	25	375

Sum = 63425

Distances from:
Doors 1 to check-in = 107 m
Doors 2 to check-in = 50 m
Doors 3 to check-in = 17 m

Mean distance from doors to check-in = 58 m

Sum of distances d ik = 135 m

Passenger volumes visiting concessions = 250

$$\text{Accessibility index for domestic sector} = \frac{250 * 135}{63425} = 0.53$$

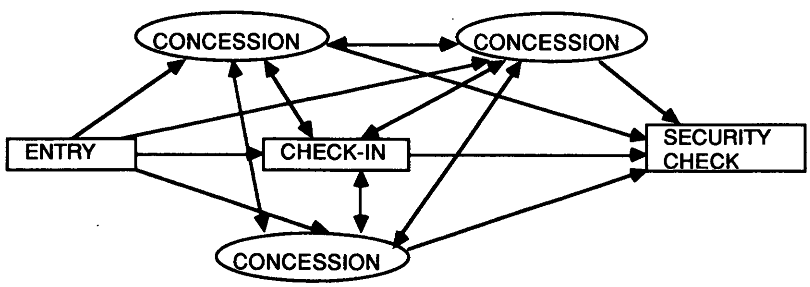

FIGURE 2 **Hypothetical enplaning process.**

$$V_g = \frac{L_o}{L_r} \times 100 \text{ percent} \tag{5}$$

In the present case,

$L_o = (1 + 1 + 1) + (3 + 4 + 1) = 11$
$L_r = 6^2 - 3(6) + 3 - 1 = 20$
$V_g = 11/20 * 100 \text{ percent} = 55 \text{ percent}$

Orientation for Part A

Part A is concerned with primary activities, and the orientation index V represents the effectiveness of the signs and information during the enplaning and deplaning process. That is,

Total observed number of sight lines in Part A (L_A)
$= \sum V$ of cells for which visibility is required in A (6)

Required number of visibility lines in Part A (L_{rA})
$= K(K - 1) - (K - 1)^2$ (7)

where $K(K - 1)$ is the number of cells in Part A of matrix, and $(K - 1)^2$ is the number of cells for which visibility is not required because of Assumption 3.

The orientation index for Part A (V_A) is defined as

$$V_A = \frac{L_A}{L_{rA}} \times 100 \text{ percent} \tag{8}$$

In the present case,

$L_{rA} = 3(3 - 1) - (3 - 1)^2 = 2$
$L_A = 2$
$V_A = (2 \div 2) \times 100 \text{ percent} = 100 \text{ percent}$

Orientation for Part B

Part B corresponds to the effectiveness of the information system for orienting passengers between primary and secondary activities. That is,

Total observed number of visibility lines in Part B (L_B)
$= \sum V$ of cells for which visibility is required in B (9)

Maximum number of visibility lines in Part B (L_{rB})
$= 2(JK) - 2(N - K)$
$= 2(JK) - 2J$ (10)

where $2(JK)$ is the number of cells in Part B of matrix, and $2J$ is the number of cells for which visibility is not required because of Assumptions 4 and 5.

The orientation index for Part B is defined as

$$V_B = \frac{L_B}{L_{rB}} \times 100 \text{ percent} \tag{11}$$

From the preceding example,

$L_{rB} = 2(3 \times 3) - 2(3) = 12$

To node

From node	1	2	3	4	5	6	$V_{\text{upper triangle}}$
1		1	–	1	0	1	3
2	–		1	1	1	1	4
3	–	–		–	–	–	–
4	–	0	0		1	0	1
5	–	0	1	1		0	0
6	–	1	0	0	0		
$V_{\text{lower triangle}}$	–	1	1	1	0		

FIGURE 3 Visibility matrix.

$L_B = 7$
$V_B = 7 \div 12 \times 100 \text{ percent} = 58 \text{ percent}$

Orientation for Part C

Part C evaluates the visibility of secondary activities from one another. That is,

Required number of visibility lines in Part C (L_{rC})
$= J(J - 1)$ (12)

Total observed number of visibility lines in Part C (L_C)
$= \sum V$ of cells in C (13)

The orientation index for Part C V_C is defined as

$$V_C = \frac{L_C}{L_{rC}} \times 100 \text{ percent} \tag{14}$$

From the example,

$L_{rC} = 3(3 - 1) = 6$
$L_C = 2$
$V_C = (2 \div 6) \times 100 \text{ percent} = 33 \text{ percent}$

LOSs in relation to orientation are defined as

LOS	PI_v *(%)*
A	90–100
B	70–89
C	40–69
D	20–39
E	10–19
F	0–9

According to the preceding LOS definitions, the global orientation in the example can be classified as LOS C. If primary activities are considered independently, LOS is A, meaning that passengers can orient themselves very easily with the existing signs and information. LOS D, derived for Part B, indicates a deficiency in the signing to guide passengers between secondary activities.

Occupancy

The continued reliance on occupancy as a performance indicator is partly attributable to the assumption that passenger comfort is directly proportional to the level of congestion. This assumption may be true in corridors when all persons are moving or in queuing areas when all persons are stationary. When passengers are carrying luggage or when there are stationary as well as moving passengers in the same area, however, density in passengers per unit area will not necessarily govern the degrees of freedom available for movement. Even if a small share of these people wished to move, they would not be able to do so with the desired level of ease. Thus, until appropriate adjustment factors are developed, LOS in the subsystems will need to be assessed according to the existing criteria.

The following criteria are suggested by AACC/IATA (*5*) for assessing check-in area LOS when PI_a is defined as

$$PI_a = \frac{A}{p} \quad (15)$$

where A is the effective floor area in the subsystem (in square meters), and p is the passenger accumulation in the same area.

LOS	*PI_a (m^2/person)*
A	1.8
B	1.6
C	1.4
D	1.2
E	1.0
F	system breakdown

Waiting Time

The British Airport Authority (BAA) has established time-based criteria for evaluating processing subsystems. Instead of the traditional six-level scheme, these criteria take the form of reliability measures. For example, the criterion for check-in facilities is less than 3 min of waiting 95 percent of the time.

Mumayiz and Ashford (*10*) categorized delay in a much broader form than BAA by defining three levels of service according to passenger perception of delay. The levels for check-in subsystems for scheduled long-haul flights, for example, are defined as

LOS	*PI_t (min)*
A (good)	<15
B (tolerable)	15–25
C (bad)	>25

PI_t is the performance indicator for time.

CONCLUSIONS

A set of indexes for evaluating terminal quality of service in relation to user needs has been presented. Such user-related performance indexes are extremely important from marketing and operational points of view. These indexes enable airport authorities to compare their systems with others and to examine the effect of operational and physical changes on system performance. The deficient elements in a system can be identified readily and corrected before they can affect user comfort.

Except for walking distance and accessibility, which are not truly independent, the six indicators are sufficient for management to assess the quality of service. Yet there is a need for a comprehensive or composite index that would enable all the subsystems to be considered as a whole unit. A composite index is especially important if the authorities are looking at strategies for alternative terminal improvement.

The intervals for each performance index have been specified arbitrarily. Such limits and acceptable performance levels can be addressed only through extensive attitudinal surveys.

Despite these drawbacks, the proposed method sets the stage for more research on this subject, and the findings demonstrate that measures other than density could be brought into the evaluation process. When pressure is mounting on authorities to increase the efficiency of terminals, this framework allows the expected consequences to be evaluated before authorities implement a particular strategy.

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Evaluation of Transportation Level of Service Using Fuzzy Sets

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The literature on transportation level-of-service (LOS) evaluation indicates a strong impetus to move away from a strictly capacity/volume- or time/space-based measure to one that directly incorporates the perception of passengers. The difficulty has been that whereas such quantitative measures are reasonably simple to measure, other LOS attributes related to convenience and comfort are qualitative in nature. Such attributes obviously are better expressed in qualitative terms. A review of the literature indicates that suggested methodologies fail to incorporate directly passengers' service perceptions, as expressed in natural language. The use of fuzzy set theory, particularly linguistic fuzzy set models, as a technique for evaluating transportation LOSs is explored. An approach for evaluating airport passenger services using linguistic variables and fuzzy sets is presented. LOS is conceptualized as a hierarchical service system with subcomponents. An example of the model applied to an evaluation of airport terminal services is presented.

Although the evaluation presented in this paper can be applied to evaluate the level of service (LOS) of other modes of transport, the discussion centers on air transport, particularly airport service evaluation. Airport landside LOS evaluation has attained renewed interest in literature and is now recognized as an area needing urgent innovative research. This need is demonstrated in the FAA/TRB study on airport performance measures (*1*).

Measurement of system performance is important in assisting operational management with current airport system capacity, facilities, and services and for planning extra capacity. It has been noted that previous design standards established as measures of LOS and capacity took limited account of the balance between demand and supply. The methodology used is not transparent (i.e., no explicit indication is given on how LOS standards were derived). The wave of privatization and deregulation experienced within the aviation industry also has given a new impetus for competition among airports and a need for customer-oriented management of airport facilities and services. Continuous growth in demand must be met with both extra capacity, where necessary, and improved current standards of service. Achieving improved service management requires that other methods be established for LOS assessment and specification of standards; new methods must be developed that consider the cited limitations of current standards. The definition of user-based LOS is the quality and condition of service of a functional component or group of functional components as experienced by the users (*2*).

This paper concentrates on developing a methodology for establishing LOS measures based on users' perceptions. To develop this evaluation method, the paper first examines previous methods of transportation (i.e., LOS) evaluation, with particular reference to airport landside LOS. Research in other domains, particularly fuzzy concepts, is explored. It is noted that LOS from a user's point of view is a fuzzy concept that the individual can best describe verbally in imprecise terms only, even though planners prefer precise, quantifiable descriptions. This paper presents the necessary fuzzy set theory relevant to the proposed methodology, looks at an application of the methodology, and provides conclusions on the usefulness of the proposed method and areas for further research.

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REVIEW OF LOS EVALUATION METHODS

Previous literature contains only a few methods of LOS evaluation. The pre-1980 approach to LOS evaluation was based on establishing LOS standards for highway transport services, passenger terminals, and pedestrian walkways. These earlier standards defined LOS at a facility by area per person available at that facility at a given time (*3*). These standards are criticized for being based on either space-volume (i.e., space standards) or time-volume (i.e., time standards). Normally at a given facility, time and space interact, resulting in such LOS aspects as overcrowding.

The most important criticism of established standards is that they are unable to incorporate directly passengers' perceptions of LOS. Since the early 1980s, research on methods for evaluating LOS that incorporates passenger perception has gain renewed interest. User-based approaches for evaluating LOS, as identified in the literature, include a passenger perception response (P-R) model reported by Mumayiz and Ashford (*4*), a utility-based model reported by Omer and Khan (*5*), and models drawn from psychological scaling techniques reported by Mueller and Gosling (*6*) and Ndoh and Ashford (*7*). These approaches are also reviewed elsewhere (*7*). The cited approaches provide crisp scale values of LOS that cannot be given linguistic values that are precise in comparison with the manner in which passengers originally expressed their perceptions of services. In most instructions on surveys to identify users' perceptions of service, linguistic values typically are used. Common terms used to obtain LOS perception include *outstanding, good, acceptable, fair, and poor*. The quest for a method for evaluating passengers' perceptions of LOS is actually a quest for a way to best model the responses given by passengers in natural language. The methodology proposed in this paper provides such a framework for modeling linguistic variables using linguistic fuzzy set theory.

Other important background issues on LOS evaluation are identifying the important factors that determine LOS of any service system component and specifying an index of measure of the service level (*8*). Lemer (*1*) summarized the main LOS index measures, accounting for the views of passengers, airlines, government bodies, airport operators, and the community at large. Odoni and de Neufville recommend that passengers dwell times within the terminal be used as the basis for evaluating passenger perception of terminal LOS (*9*). Seneviratne and Martel found the following six factors to be determinants of LOS in the processing, holding, and waiting components of the airport: (a) information, (b) waiting time (for processing activities), (c) convenience (i.e., physical effort required for processing activities), (d) availability of seats, (e) concessions (i.e., variety and accessibility), and (f) internal environment (i.e., aesthetics and climate). The findings were drawn from a summer survey of departing passengers at Dorval International Airport in Montreal (*10*). Techniques for determining the importance rating of various LOS attributes can be improved using fuzzy set methods (*11,12*). The proposed evaluation method in this paper allows the direct incorporation of passenger perception of the importance of any service attribute within the evaluation scheme.

Elements of Fuzzy Set Theory

Fuzzy set theory was introduced by Zadeh (*13*) as a means of modeling ill-defined problems; since its inception, it has been applied in a wide variety of fields that need to deal with imprecise quantities (*14–17*). Fuzzy set theory is a generalization of ordinary set theory, providing an adequate conceptual framework and serving as a mathematical tool for analyzing practical problems that often are obscure, vague, or indistinct. This section summarizes some fundamental definitions and operations of fuzzy set theory that will be used in this paper. Further exposition on this subject can be found in other literature (*13,18*).

Linguistic Variables

It was noted previously that passengers often use qualitative terms to describe their perceptions of transportation LOS. The term "LOS" is considered a linguistic variable in this paper; a linguistic variable is defined as a variable, the values of which are words, phrases, or sentences, in a given language that can be either natural or artificial (*19*). For example, the overall LOS within the airport terminal can be considered a linguistic variable with meaningful natural language classification such as excellent, good, acceptable, poor, bad, or unacceptable. These words form a term set, or primary terms useful in defining passenger perception of LOS. The primary terms are themselves imprecise and can be qualified further using natural language qualifiers (or hedges), such as very, fairly, or highly, in order to provide more precise meaning to the perceived service quality. [The concept of hedges is very important and useful in linguistic variable computation. A hedge acts as a modifier of the primary term. For example, the hedge "very" intensifies the particular word with which it is used. Thus, if that hedge is applied to the linguistic value $A = low$ such that the value becomes "very low," it decreases the fuzziness of the elements of the linguistic value "low" by decreasing its membership grade. The intensification of A is expressed as INT(A). Other useful operations on linguistic variables include concentration, CON(A); dilation, DIL(A); normalization, NORM(A); fuzzification, SF(A,K); and shift on A and fuzzy set removal.]

Let X be a universe of discourse, or a set with elements x, where X is defined with respect to LOS evaluation, and let A be a subset of X. If each element, x, is associated with a membership value $\mu_A(x)$ within the subset A, then A is a fuzzy set. The membership grade is constrained in the interval [0,1]. Thus, in general, any subset A may be represented by m discrete values, $x_1, \ldots, x_m$, and m membership values, $\mu_A(x_m)$. That is,

$$A = [x_1 \mid \mu_A(x_1), x_2 \mid \mu_A(x_2), \ldots, x_m \mid \mu_A(x_m)] \quad (1a)$$

where = means "defined to be" and | is a delimiter.

The main computation of linguistic variables of interest here are fuzzy set addition, multiplication, division, min/max operations, and a measure of distance between fuzzy sets.

If A and B are two fuzzy subsets of the universes X and Y, with elements x and y, respectively, such that

$$A = [x \mid \mu_A(x), 1 \leq x \leq 9] \quad \text{for all } x \text{ that belongs in } X \quad (1b)$$

and

$$B = [y \mid \mu_B(y), 1 \leq y \leq 9] \quad \text{for all } y \text{ that belongs in } Y \quad (1c)$$

then fuzzy addition is defined as

$$\mu_{A+B}(z) = [\max \{\mu_A(x) \min \mu_B(y)\}] \quad (2a)$$

where

$$(x + y) = z$$

$$1 \leq z \leq 9$$

[Computationally, Equation 2a means that to calculate the degree of membership of z, in $A + B$, one must examine all possible ways that two elements (x, y) can sum to z and examine the degree of membership for the pairs adding to z. The membership grade assigned to z, $\mu(A + B)(z)$, is the maximum possible membership value from the pairwise combination of x and y.]

Also, fuzzy multiplication is defined as

$$\mu_{A*B}(z) = [\max \{\mu_A(x) \min \mu_B(y)\}] \quad (2b)$$

For example, given A and B as

$$A = \text{low} = [0|1.0, 1|1.0, 2|0.6, 3|0.3, 4|0.1, 5|0.0, 6|0.0]$$

and

$$B = \text{medium} = [0|0.0, 1|0.0, 2|0.6, 3|1.0, 4|0.5, 5|0.2, 6|0.1]$$

then, applying Equations 2a and 2b,

$$A(+)B = [2|0.6, 3|1, 4|1, 5|0.6, 6|0.5, 7|0.3, 8|0.3, 9|0.1, 10|0.1, 11|0]$$

and

$$A(*)B = [0|1, 1|0, 2|0.6, 3|1.0, 4|0.6, 5|0.2, 6|0.6, \ldots, 36|0.0]$$

Figure 1 depicts the addition of fuzzy sets A and B. The use of hedges is another useful manipulation tool for modifying linguistic variables. One such factoring scheme is proposed by Zadeh for linguistic values (*20*). For example, given the following definitions for linguistic quantities large, medium, and small,

$$\text{Large} = [0.8|0.5, 0.9|0.9, 1|1.0]$$

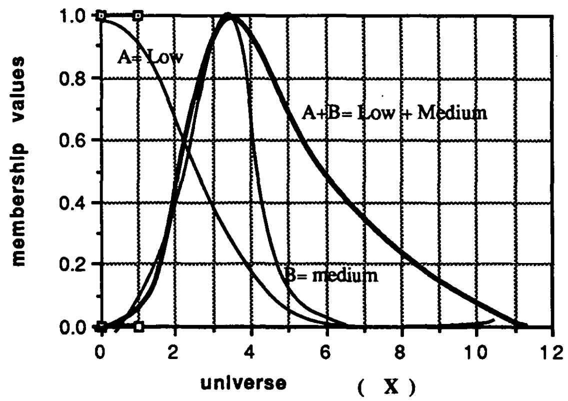

FIGURE 1 Illustration of fuzzy set addition of A and B.

Medium = [0.3|0.2, 0.4|0.8, 0.5|1.0, 0.6|0.8, 0.7|0.2]

Small = [0|1, 0.1|0.9, 0.2|0.5]

then very large, quite small, and very small can be defined as

Very large = $(\text{large})^2$ = [0.8|0.25, 0.9|0.81, 1|1.0],

Quite small = $(\text{small})^{5/4}$ = [0|1, 0.1|0.88, 0.2|0.42], and

Very small = $(\text{small})^2$ = [0|1, 0.1|0.81, 0.2|0.25].

Thus, using a similar factoring scheme, it is possible for an analyst to define different intensity for a given linguistic quantity.

FRAMEWORK FOR SERVICE SYSTEM LOS EVALUATION

The structure of the LOS evaluation proposed is depicted in Figure 2. The structure represents a hierarchical service system decomposed into its component service attributes, each of which can be associated with a linguistic variable name. Thus, at the highest level of the hierarchy is the node representing the overall LOS of the service system; the next level below indicates the service attributes at this level. Further decomposition of the service system can be represented at lower levels, depending on the size of the system being evaluated.

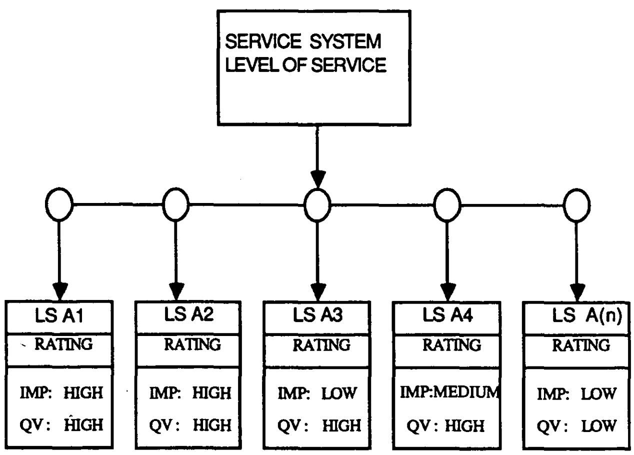

FIGURE 2 Schematic diagram depicting a service system.

For the design of the fuzzy LOS model, the existing service system initially must be evaluated by the users. At each system sublevel, information is required on the importance of each particular attribute to the evaluation of the service quality. In this approach, the values for the importance rating and quality of service are expressed as linguistic quantities, or fuzzy linguistic values. In Figure 2 a hypothetical evaluation is shown with attribute LS $A1$ evaluated as having an importance rating of high and a quality of service value of medium. These two quantities are the fuzzy values that define the linguistic variable LOS of LS $A1$.

The importance rating provides a fuzzy weight for each attribute, or LOS component LS(i). Weights or importance ratings can be determined using existing techniques, as given by Saaty (*11*), and other market research methods, such as conjoint analysis. A generalized tree structure to evaluate an airport service system is shown in Figure 3. A similar structure can be designed to evaluate airline and other transportation services. Before the service system evaluator is modeled, the the linguistic variables, fuzzy subset for each variable, and membership grade for each fuzzy term must be defined. For instance, the facility check-in can be assigned linguistic variables *check-in time* and *waiting time*, with both variables assigned three fuzzy subset values: acceptable, tolerable, and unacceptable. The universe of the fuzzy set then is defined on both the check-in time and waiting time on the time scale. The system analyst also has to provide, a priori, a membership function for each fuzzy value. This step is vital because the membership values give meaning to each fuzzy value; that is, membership values restrain the fuzzy values to the universe of discourse. Zimmerman (*12*) provides empirical research on membership functions and definitions. This application suggests that in the case of passengers, a membership grade can be obtained at any service component if there is a physical quantity that can be related to that component. In work by Mumayiz and Ashford (*4*), the obtained P-R models indicate the existence of possible membership grade for each of the three linguistic values used, that is, good, tolerable, and bad, over the universe of processing times for different service components within the terminal. A linguistic variable, such as check-in time LOS, can be conceptualized, and it is evaluated using the primary terms *good*, *tolerable*, and *bad*. A linguistic variable for time-based service can be defined for most processing activities (Figure 3) with a time scale as the universe of discourse. At holding facilities, suggested linguistic variables include *crowding*, *comfort*, *visual interest*, and *waiting time*, defined by using a time and space scale as the universe. At circulatory facilities, suggested linguistic variables include *walking distance*, *directness*, *signing*, and *ease of transiting*, also defined by using distance and time scale measures as the universe. Because there are many possible variables for defining LOS at a particular facility, the expert needs to establish if-then heuristic rules that relate the "if" conditions at a given facility with "then" consequences, that is, LOS at the facility. For instance, a simple rule for LOS at check-in processing can be expressed: if the check-in time is acceptable and the queue space is acceptable, then LOS at check-in is acceptable.

The computation of the overall system LOS can be achieved using a model proposed by Zadeh (*20*) (Equation 3), which enables the computation of fuzzy weighted means at each level of the service system. (An alternative method for aggregating fuzzy measures of LOS is the use of Sugeno's fuzzy integral. In a system with n attributes that have known LOS measures (h_i) and weights (w_i), the overall LOS of the system using fuzzy integral is defined as $\{\max [\min (h_i, w_i)]\}$ (*21*).)

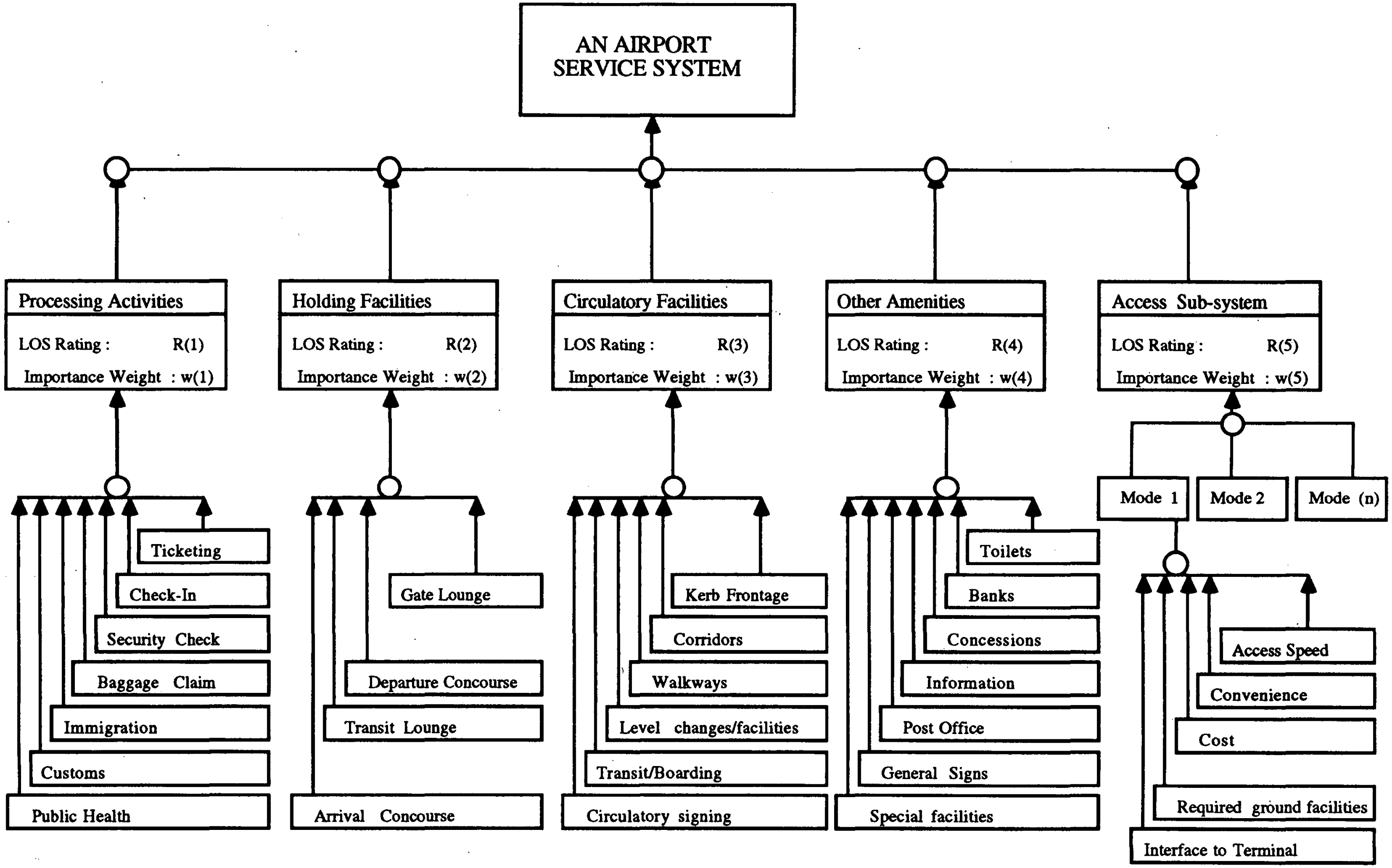

FIGURE 3 **Airport service system.**

Using this Equation 3, the overall LOS of the service system can be defined as a fuzzy mean Z:

$$Z_j = \sum_i^n \{[W_i] * [L_i]\} / \{\sum_i^n [W_i]\} \tag{3}$$

where

n = number of component i's at Level j,
$[W_i]$ = fuzzy weight, or importance factor, of component i at Level j, and
L_i = fuzzy quality of service component i at Level j.

The mean fuzzy set value also can be defined over m evaluators, or users of the service system. Having obtained a mean fuzzy value for the service system or its component, it is necessary to give a linguistic meaning to this value such that we can describe the system's overall LOS in words such as excellent or poor.

Linguistic Approximation of LOS Measures

It is required that the overall LOS definition of the service system be stated in natural language rather than fuzzy quantities. Thus, translating the obtained mean fuzzy value into its equivalent primary linguistic term is needed. Three main methods are provided in the literature: a measure of the Euclidean distance or best-fit method, successive approximation, and piecewise decomposition (*14*). The best-fit method is recommended when the number of the primary term set is small; when the primary term set is large the successive approximation method can be used. [The successive approximation method first assumes there are two close primary terms before various expressions are applied to these two points in order to approximate the closest natural language expression for the mean fuzzy value. The piecewise decomposition method, however, divides the linguistic variable into intervals. Each interval is combined with one of the standard logical connectors (e.g., *or* and *and*) to approximate the natural language expression.] Obtaining the approximate natural language expression is known as approximate reasoning or linguistic approximation. For this application, the best-fit approach is recommended. Given a fuzzy set Z, for which a natural language approximation will be computed later in this paper, and a known fuzzy set A representing one of the natural language expressions used for rating LOS, then the distance D between Z and A can be computed as follows:

$$D(Z, A) = \left(\sum_{l=1}^{k} \{[\mu_Z(i) - \mu_A(i)]\}^2\right)^{0.5} \tag{4}$$

where

$D(Z,A)$ = Euclidean distance between fuzzy sets Z and A;
$\mu_Z(i)$, $\mu_A(i)$ = membership values for elements i of Z and i of A, respectively;
k = integer that defines the highest element in value in fuzzy sets of Z and A.

The calculation of Equation 4 is performed for all the expressions in rating natural language. The natural language expression that produces the shortest Euclidean distance from Z is taken to be the best fit to Z and is used as its natural language equivalent.

Application of Methodology

The proposed methodology is illustrated using a simplified application to evaluate processing services at an airport. The modeling procedure is summarized as follows:

1. Identify clearly and classify the service system as a decision tree (as in Figure 3), indicating the component of the system at each level and the appropriate linguistic variables that can be used to describe a particular facility.
2. Define the natural language fuzzy subset for each variable appropriate for defining the level of service for each component of the service system.
3. Define the universe of discourse (X) to be used to give values to the linguistic variable and also define the membership grade for each of the linguistic fuzzy values over the universe of discourse. Where hedges apply, define the factoring required to modify the primary terms using the defined hedge. A time/space measure can be used in the stated example.
4. Obtain an evaluation of the system from users or experts for all components of the system for which such an evaluation is stated, using one of the linguistic values already defined as well as an indication of the importance of each particular component to the overall LOS of the service system.
5. Determine the mean fuzzy value of the system, given Number 4 and translate the obtained fuzzy value into its approximate natural language expression.
6. Establish procedural rules for LOS system evaluation. The objective is to implement the rules into a computerized advisory system that can be simulated for different policy options as well as predict the LOS conditions within the terminal. A program in C can then be developed in order to implement both the fuzzy set computations and procedural rules, with graphic enhancement to the output, displaying the changing state of the service system and its component over time.

To illustrate the preceding methodology, a subsystem of Figure 3 is evaluated, that is, the processing activity subsystem for departures with just three components: check-in, security, and passport control. The final level of services at these components are assumed to be low, medium, or high without the heuristic rules, while the universe is defined as the set {0,1,2,3,4,5,6,7,8,9,10}. This set can be translated into timespace measures relating to the terminal, with a high set value associated with a high disutility in service quality. To ease the manual computation, the set is restricted to {0,1,2,3,4}. The following natural language expressions and corresponding fuzzy set values are defined for each of the processing activity components:

Check-in:

$$\begin{aligned} \text{Low} &= (Lc) = \{0|0.0,\ 1|0.1,\ 2|0.8,\ 3|1.0,\ 4|1.0\} \\ \text{Medium} &= (Mc) = \{0|0.0,\ 1|0.7,\ 2|1.0,\ 3|0.3,\ 4|0.0\} \\ \text{High} &= (Hc) = \{0|1.0,\ 1|0.5,\ 2|0.1,\ 3|0.0,\ 4|0.0\} \end{aligned} \tag{5}$$

Security:

$$\begin{aligned} \text{Low} &= (Ls) = \{0|0.0,\ 1|0.6,\ 2|1.0,\ 3|1.0,\ 4|1.0\} \\ \text{Medium} &= (Ms) = \{0|0.0,\ 1|1.0,\ 2|0.1,\ 3|0.0,\ 4|0.0\} \\ \text{High} &= (Hs) = \{0|1.0,\ 1|0.1,\ 2|0.0,\ 3|0.0,\ 4|0.0\} \end{aligned} \tag{6}$$

Passport:

$$\begin{aligned} \text{Low} &= (Lp) = \{0|0.0,\ 1|0.5,\ 2|1.0,\ 3|1.0,\ 4|1.0\} \\ \text{Medium} &= (Mp) = \{0|0.0,\ 1|1.0,\ 2|0.1,\ 3|0.0,\ 4|0.0\} \\ \text{High} &= (Hp) = \{0|1.0,\ 1|0.2,\ 2|0.1,\ 3|0.0,\ 4|0.0\} \end{aligned} \tag{7}$$

LOS at the processing activity node is defined a priori as

Processing activity node:

$$\text{Low} = (L\text{pa}) = \{0|0.0,\ 1|0.5,\ 2|1.0,\ 3|1.0,\ 4|1.0\}$$

$$\text{Medium} = (M\text{pa}) = \{0|0.0,\ 1|1.0,\ 2|0.1,\ 3|0.3,\ 4|0.0\}$$

$$\text{High} = (H\text{pa}) = \{0|1.0,\ 1|0.2,\ 2|0.1,\ 3|0.0,\ 4|0.0\} \quad (8)$$

Importance weights also need to be defined for the system. Typically for transport services, if an attribute or component is performing well, it is less likely to be perceived by its users as being important relative to other components, and vice versa. Thus, the importance level similarly should be defined as fuzzy quantities rather than as crisp weights. For this example, the fuzzy values for importance weight are defined as low (Li), medium (Mi), and high (Hi) where

$$Li = \{0|0,\ 1|0.0,\ 2|0.1,\ 3|0.5,\ 4|1.0\}$$

$$Mi = \{0|0,\ 1|0.1,\ 2|1.0,\ 3|0.1,\ 4|0.0\}$$

$$Hi = \{0|1,\ 1|0.5,\ 2|0.1,\ 3|0.0,\ 4|0.0\} \quad (9)$$

Assuming the components of the processing activities are evaluated in natural language as

LOS at check-in = low = Lc

Importance weight = Hi

LOS at security = high = Hs

Weight = Hi (9a)

LOS at passport control = medium = Mp

Weight = Li (9b)

Then the overall LOS associated with the subsystem can be computed using Equation 3 as

$$Z = \{Lc * Hi + Hs * Hi + Mp * Li\} / \{Hi + Hi + Li\} \quad (10)$$

Evaluating Equation 10 needs the application of fuzzy set addition, multiplication, and division as defined and illustrated earlier in the paper (Equations 1 and 2). $Lc * Hi$, $Hs * Hi$, $Mp * Li$, and $(Hi + Hi + Li)$ therefore are computed using Equations 5 through 9, as follows:

$$Lc * Hi = \{0|1.0,\ 1|0.0,\ 2|0.5,\ 3|0.5,\ 4|0.5,\ 5|0.1,\ 6|0.1,\ 7|0.1,\ 8|0.1,\ 9|0,\ 10|0\}$$

$$Hs * Hi = \{0|1.0,\ 1|0.1,\ 2|0.1,\ 3|0.0,\ 4|0.0,\ 5|0.0\}$$

$$Mp * Li = \{0|0.0,\ 1|0.0,\ 2|0.1,\ 3|0.5,\ 4|1.0,\ 5|0.5,\ 6|0.1,\ 7|0.1,\ 8|0.1,\ 9|0.0\}$$

$$(Hi + Hi + Li) = \{0|0.0,\ 1|0.0,\ 2|0.1,\ 3|0.5,\ 4|1.0,\ 5|0.5,\ 6|0.1,\ 7|0.1,\ 8|0.1,\ 9|0.1\}$$

Performing the division required in Equation 10, the obtained LOS of the processing activity subsystem is computed as

$$Z = \{0|0.0,\ 1|0.5,\ 2|0.5,\ 3|0.5,\ 4|0.1,\ 5|0.1,\ 6|0.1,\ 7|0.1,\ 8|0.1,\ 9|0.0\}$$

Z needs to be normalized by adjusting the degree of membership of its elements so that at least one element has a membership value of 1 in the set. [A fuzzy set is normalized by adjusting the degree of membership of the elements such that at least one element has the value of 1 in the set. The concept of convexity (also known as convex closure) means adjusting the membership values of a fuzzy set upward, if necessary, to ensure a relatively smooth curve so as to avoid any discontinuities in the fuzzy set function.] Furthermore, restricting the set in the interval {0,1,2,3,4}, Z normalized is

$$Z = \{0|0,\ 1|1.0,\ 2|1.0,\ 3|1.0,\ 4|0.2\}$$

Next, Z is translated into its approximate natural language equivalent. To accomplish this, Equations 4 and 8 are applied to find the shortest distance $D(Z, A)$ between Z and the primary terms Lpa, Mpa, and Hpa. Substituting membership values from Z and A into Equation 4,

$$D(Z, L\text{pa}) = \{(0-0)^2 + (1-0)^2 + (1-0.1)^2 + (1-0.5)^2 + (0.2-1)^2\}^{0.5} = 1.643$$

$$D(Z, M\text{pa}) = \{(0-0)^2 + (1-0.1)^2 + (1-1.0)^2 + (1-0.1)^2 + (0.2-0)^2\}^{0.5} = 1.288$$

$$D(Z, H\text{pa}) = \{(0-1)^2 + (1-0.5)^2 + (1-0.1)^2 + (1-0.0)^2 + (0.2-0)^2\}^{0.5} = 1.761$$

Thus, the natural language approximation to describe the observed LOS at the subsystem (i.e., processing activity subsystem) is medium. This approximation can be attributed to the low LOS given to check-in, which has a high importance rating. The approximate value of medium is also closer to low (Lpa) than Hpa. This fact implies that by using hedges, the approximate value of Z as determined can be refined such that $D(Z,A)$ is minimized further.

CONCLUSIONS

For most service industries, the need to meet the client's requirements satisfactorily is a key management objective to successful business. This objective requires regular assessment of LOS to ensure that high standards are maintained. A major requirement for any technique used is the need to measure the various attributes of the service system according to its effectiveness to meet customers' requirements satisfactorily. It is shown that existing methods of measuring LOS, particularly in air transport, have limitations in that each method attempts to provide a crisp value measure that does not translate easily to the subjective perception of the service system as seen by the user. It is also difficult to relate such weights to the original attributes of the service system.

The method proposed in this paper is the application of fuzzy set theory. This paper demonstrates how this theory can be applied to evaluate transport services using linguistic variable modeling. An advantage of developing such a system is that the modeling framework is more compatible with passengers' perceptions of the system or transport services through imprecise and vague linguistic values. Comfort and convenience are classic transport service attributes that have such subjective, imprecise meanings. Most passengers easily can express in linguistic terms their feelings on such qualitative service attributes without being able to provide a numeric assessment. The proposed methodology allows for modeling the linguistic variables provided by the users via fuzzy sets and linguistic value computation.

Although the approximate linguistic value of the airport service subsystem for the simplified illustration can be deduced, it can be seen that manual computation of the linguistic variable can be tedious. This task is made easier by the computerized implementation of the evaluation method. Such computerization can enhance the development of the methodology into an *expert* LOS assessment system, with better refinement of the service levels, including LOS graphics display capabilities. Further research therefore is needed to enhance the computerized methodology as well as research to establish the membership function for the various components and subsystems of a service system, such as an airport. The ability to report service level through users' perceptions is the major strength of this technique. The computerized model can be extended and applied to other transport problems involving multicriteria decision analysis. Once a fuzzy model of service perception has been defined, this model can be used for evaluating daily service quality. It also can be used for checking new system designs without the need to repeat the measurements of service preception.

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Information System for Operations at Medium-Sized Airports

D. GILLINGWATER, N. ASHFORD, AND J. SHELTON

A systems analysis of the information requirements of a medium-sized airport, which serves between 1 million and 5 million passengers per year, is presented. The proposed generic model of an airport information system (APIS) is based on this systems analysis and an evaluation of existing interactive software and hardware systems used at airports. Research was undertaken in collaboration with East Midlands International Airport (U.K.), together with Amsterdam-Schiphol Airport (The Netherlands), Frankfurt Airport (Germany), and Vienna Airport (Austria). The information requirements of an airport information system, developed using an approach based on structured systems analysis and design methods (SSADM), are described. Topics include an account of airport information system functions and system design objectives, definition and development of a generic model of APIS, and conclusions drawn from the research. The main conclusion is that current airport information systems can neither meet the information requirements associated with the operation of medium-sized airports nor approximate, to the specification of APIS, the proposed generic model.

Safety and economic reasons have accounted for the increasing use of computer systems within airports. Such systems contribute directly to flight efficiency by rapidly and economically coordinating flight preparations and by checking completed and ongoing operations. Airport authorities need to cater not only to their own interests but also, as partners with airlines and many other airport-reliant businesses, to the interests of their clients.

Airports thus may be viewed as concentrated networks of diverse but complex activities that link passengers and cargo to aircraft arrivals and departures. As such, they generate and require considerable amounts of information and are excellent examples of "information-rich" environments. Until recently, airports have relied on a variety of means to organize and manage this information and the flows that are generated. For medium-sized airports, which serve between 1 million and 5 million passengers a year, information transfer and information management have relied as much on manual paper-driven systems as on electronic data processing.

Subsystems have been created, typically on functional lines (e.g., to cope with financial accounts and passenger information), that essentially are separate entities. As a consequence, there is evidence of information duplication between subsystems and a reliance on personal communication and information transfer at the interfaces. The take-up of information technology (IT) has been comparatively slow and largely uncoordinated, at least in IT planning terms. The take-up has been driven mainly by the twin imperatives of internal financial management and external pressure from airlines. The overall view is that airport management have proceeded extremely cautiously with the implementation of IT.

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The main portion of this paper is based on a 2-year grant-aided study, with the following objectives:

- To undertake a systems analysis of the information requirements of medium-sized airports,
- To develop a generic model of an information system, and
- To evaluate existing interactive IT systems in collaboration with East Midlands International Airport (U.K.), together with Amsterdam-Schiphol Airport (The Netherlands), Frankfurt Airport (Germany), and Vienna Airport (Austria).

Designing a complex IT application such as an airport information system has many methodological difficulties. Given the checkered history of system design, it is hardly surprising, perhaps, to discover a degree of skepticism among airport managers about the ability of a single information system to meet the requirements of their diverse operations. That said, there still is strong anecdotal evidence that suggests considerable duplication of effort. In addition, many airport managers believe that airports are not unique undertakings and, as a result, that it is not necessary to search for problems and solutions specific to airports.

The research reported here leads to a different conclusion. The choice does not appear to be as stark as is often presented: either minimize initial outlay by purchasing proprietary business applications that may be capable of modification or get the system that is wanted by hiring a software consultant to design and deliver a system ab initio.

There is a third, preferable course to take: develop a *generic* solution that exploits the benefits of proprietary software and yields a design that airport managers will find familiar and want to use. For this to succeed, several preconditions must be met. First, the heavy development costs must be shared because they are beyond the capacity of an individual airport to fund from its own resources. Second, close involvement and collaboration are required on the part of the users (i.e., airport managers). Third, system analysts and software engineers are needed to produce the application.

A particular system design methodology has evolved, partly in response to such issues. Called the structured systems analysis and design method (SSADM), it is rapidly becoming a standard method for the analysis and design of information systems in the United Kingdom and elsewhere (*1*).

For these reasons, this research has tried to follow the discipline of SSADM an approach. As Downs et al. (*2*) make clear, SSADM is *prescriptive*, because it sets out the way in which a systems development effort should be conducted, and *reductionist*, because it breaks down a project into phases that are then divided into stages and subdivided into steps (with each step having a list of tasks, inputs, and outputs). Finally, Downs et al. (*2*) clarify that SSADM provides structural and procedural *standards*, covering everything from diagram notation and syntax to the conduct of interviews.

SSADM is a data-driven approach to system design and development that views problems from a data base management perspective. This approach follows the basic assumption that systems have an underlying, generic data structure that changes little over time, even though processing requirements may change. It also recognizes that there probably will be different views as to how a system's information requirements can best be met; for example, SSADM places great emphasis on the need to cross-check between different views for consistency and completeness. Finally, SSADM separates logical descriptions of a system from the physical aspects of development, converting a logical system to a physical design as late as possible, ". . . when the 'cost to fix' any errors is low but their potential impact very high" (*2*).

The structure of the method can be described as follows:

Stage 1. The current system, in its current implementation, is studied first in order to gain an understanding of the environment of the new system.
Stage 2. This view of the current system is used to build the specification of the required system. However, the required system is not constrained by the way in which the current system is implemented.
Stage 3. The specification of requirements is detailed to the extent that detailed technical options can be formulated.
Stage 4. The detailed design is completed at the logical level before implementation issues are addressed.
Stage 5. The logical design is converted into physical design by the application of simple (first cut) rules. The resulting design is tuned using the technique of physical design control before implementation. (*1*)

Background information for the research was obtained from in-depth field studies. These studies were conducted by examining the existing and well-regarded information system installations at three airports: Vienna Airport's system, called MACH; Amsterdam-Schiphol Airport's system, called CISS; and Frankfurt Airport's system. Additionally, a more in-depth analysis of information flows was carried out at one airport—East Midlands International Airport—during a 6-month period. The field and related studies were carried out during an 18-month period.

INFORMATION SYSTEM FUNCTIONS AND DESIGN OBJECTIVES

An airport information system lies at the center of any airport's operations. The primary objective of such a system is to improve the overall efficiency of operations and the quality of service to passengers, airlines and service companies. In practice there are at least four core activities with information system functions of critical importance (*3*):

1. Airport Management
   –Airport management per se (e.g., building, engineering, maintenance, finance, and personnel),
   –Air traffic control,
   –Airport information desk,
   –Airside/ramp operations and apron management, and
   –Airport operations monitoring (including noise and pollution monitoring).
2. Airline and Airline Handling Agents
   –Intra-airline information (e.g., use of systems such as CUTE and SITA), and
   –Aircraft servicing (e.g., cleaning, refueling, engineering checks, and catering).
3. Public Information
   –Off-airport videotext information services (e.g., teletext and similar TV-based information), and
   –On-airport public display monitors (e.g., flight departures and arrivals).
4. Security and Immigration
   –Airport police and security, and
   –Customs and immigration authorities.

From these four core activities, it is possible to arrive at a list of nine external entities requiring access to an airport information system. In other words, these entities are the main producers and consumers of information generated and used within an airport environment. Taken together, they constitute the principal ingredients of an airport information system:

- Airport management system,
- Airline/handling agent systems,
- Air traffic control,
- Airport information desk,
- Ramp operations and apron management,
- Videotext systems,
- Public display monitors,
- Security, customs, and immigration, and
- Airport operations monitoring system.

Figure 1 shows the external entities graphically. To indicate their crucial roles, three functions are described more closely: airport management system, airline/handling agent systems, and ramp operations and apron management.

Airport Management System

The planned daily flight schedule, or "Mayfly," is of great use in manually operated systems. However, in information system terms, it is the *seasonal* flight schedule that provides the initial impetus. This schedule stores all scheduled and charter flights planned on a seasonal basis, usually during the summer and winter seasons. It contains flight details required for the daily flight schedule. The essential data are

- Planned arrivals and departures, shown by clock time (00.01 to 24.00 hr),
- Flight numbers (e.g., BY 482 A), and
- Departure and arrival gate to be used by each flight (e.g., Gate 6).

The preparation of the *daily* flight schedule, however, provides the operational pressures for airport managers. The seasonal flight schedule provides the base for this schedule, with any new but pre-planned flights normally being entered 7 working days before the departure date as a "rolling update."

Several functions therefore must be built into any flight schedule data base; they include the abilities to

- *Change* the seasonal and daily flight schedules,
- *Flag* any flight on the data base (i.e., to call it up "by exception"),
- *Print* any data in real time, and
- Automatically *delete* historical flight data.

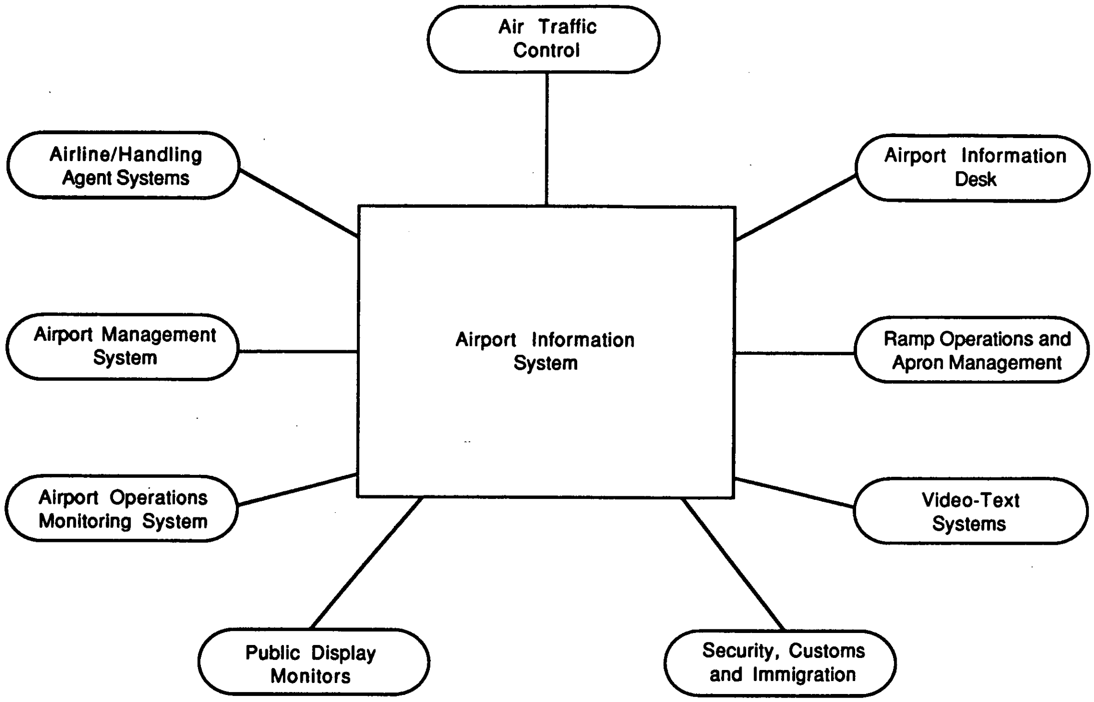

FIGURE 1 External entities.

In a multiterminal airport, dedicated terminals need to be differentiated between those giving users read-only access and those giving direct or partial access to the flight schedule data base. Where air traffic control or airport managers—and to some extent airlines—are involved, they must be able to add, delete, or modify flight data rather than have read-only access. All changes must be flagged for operational personnel. For software requirements, this function must incorporate well-defined data fields to allow, for example, causes of delay to be entered.

Flights in the daily flight schedule data base should be created automatically from the seasonal flight schedule listings where possible. Each day a "spooling-off" of the previous day's schedule should begin to form the actual daily flight schedule. This process should allow for real-time hard-copying of records to permit manual checks and to provide greater security of historical data in case of subsequent loss.

When deleting flight records is required, the data are transferred to an archive data base for flight schedules that should at least include the following:

- Airline, point of origin, and destination, including en route stops;
- Scheduled start and end dates of the flight;
- Whether the flight was a scheduled, charter, cargo, or private flight;
- Details of handling agencies involved and any problems experienced (e.g., indicated by code); and
- Any relevant information from the airport operations monitoring system (e.g., whether a flight breached current noise regulations).

In addition, the following details must be recorded to comply with current regulations:

- Scheduled arrival and departure times;
- Logged flight-plan route;
- Nature of flight (i.e., passenger, cargo, commercial civil, private civil, royal/presidential, or military); and
- Handling agencies used.

As a guide, any airport information system should be able to deal with the following methods of updating the data bases, manually via a terminal or automatically via a screen update program:

- The system must allow full-screen updates by authorized personnel only.
- Repetitive daily updates should not require user intervention (i.e., flights that repeat daily in the week should not need to be reentered daily).
- Flagging of any changes must be marked clearly for the user's benefit.

When an individual flight record is incomplete (e.g., when no "on-stand" time has been entered or the baggage handling agent is missing), airport personnel will need to access the actual daily flight schedule data base to perform remedial updating procedures. To avoid corrupting this data base, it is best for such amendments to be entered on a different data base at the flight performance monitoring stage, which will require various levels of system access to be incorporated at the design stage.

Airline/Handling Agent Systems

Given the complexity of the interfaces between airlines and their handling agents, consideration here is restricted to three particularly important functions: baggage belt handling, boarding gates, and fuel and catering.

Baggage Belt Handling

The status of baggage belt handling can be divided into four phases:

1. An arriving flight is allocated a designated belt.
2. The "first bag" is on the belt.
3. The "last bag" is on the belt.
4. The belt is cleared for reallocation to another flight.

This information must be shown on public display monitors and recorded on a data file for airport records. The relevant handling agency therefore has to have direct read-and-write access to this part of the daily flight schedule data base to allow for real-time updating. Indeed, this access is an essential requirement for the smooth and efficient running of any arrival or departure area to allow passengers to be directed correctly to their allocated baggage carousel.

Any system also must account for errors in the baggage handling system. Under normal circumstances the in-built requirement for belt displays to regulate themselves automatically would be sufficient. If no last bag is entered, for example, there needs to be a specified time lapse before the flight disappears from the allocated belt so that handling staff have time to correct any error.

Boarding Gates

There are four separate phases to the boarding gate procedure:

1. Boarding gate is declared "open."
2. Passengers board the flight.
3. Final call is announced.
4. Boarding gate is "closed."

Any status change to a flight normally is initiated by an airline employee making data entries directly into a dedicated terminal at or near the boarding gate. When any gate message is received, the exact time of the change should be both stored and highlighted so that it is readily recognizable as an alteration.

Fuel and Catering

Both an airport's "fuel farm" and the catering organization need to be linked to the airport's daily flight schedule data base, but on a read-only basis. This specification is to allow for estimated times of arrival and delays to be seen and considered when both organizations are planning or executing a daily rota. The timely arrival of refueling and catering vehicles is necessary to avoid turnaround delays when an aircraft is typically on-stand for only 45 min to 1 hr. At well-coordinated airports with comprehensive information systems, a medium-sized, 130-seat aircraft can be simultaneously refueled, restocked, and cleaned in half an hour from initial "on-blocks" time.

Ramp Operations and Apron Management

Aircraft parking and boarding-gate slots need to be allocated by the ramp marshal's office. An information system must be able to cope with these operational requirements and provide facilities for the on-line updating of the daily flight schedule data base through the following methods:

- Direct command to update a specific flight with a new gate slot and to highlight this change on screen (e.g., via reverse color modes),
- Full-screen update that alters several flights in a specified order,
- "Flagged" automatic command that shows flights and satisfies certain criteria that are entered into the daily flight-schedule data base.

The main elements of the flight schedule data base, which must be updated daily, are as follows:

- Originating airport of flight,
- Aircraft registration,
- Aircraft type,
- Public display monitors,
- Airline users (new airlines),
- Baggage handler,
- Baggage belt allocation, and
- Parking stand allocation.

These elements need to be updated fully on a rolling basis (often every few minutes) to ensure an efficient cascading of data to the finance and accounts section of the airport management system, thus allowing timely and accurate invoicing of customers.

It is most important that an accurate record of both boarding gates and parking slots is kept because, in the event of a query from an airline, records from the flight schedule archive may have to be cross-checked. In practice, many such queries result from the inaccurate entering of on-block and off-block times, which leads to incorrect charging of users. Incorrect identification of an aircraft type also can lead to under- or overcharging because of varying passenger numbers carried and varying takeoff and landing weights.

A simple data entry procedure is all that is required for ramp and apron staff for real-time updating. It has been considered that ramp staff need to be given a printer so that hard copies of the daily flight schedule can be carried around on the apron. Hand-held terminals with read-only access are a great advantage because very recent updates may be seen in real time.

The three preceding information system functions—airport management system, airline/handling agent systems, and ramp operations and apron management—indicate the complexity of the information requirements of an airport and should be incorporated in the design of an airport information system. If these entities, together with the other six external entities, constitute the main information system functions of an airport, then the next step is to identify the critical system design objectives to be met. Five such objectives would form the backbone of any airport information system design.

The first objective would be to provide an efficient fault-tolerant *information transaction system.* Such a transaction system would contain all the application software for accessing an airport's data bases, presenting terminal users with a menu-driven data base system. As such, the transaction system would interface with terminal users and the core of the data bases: the daily flight schedule. Commands to access on-line data would be given processor priority; requests for historical data would be dealt with in queued sequencing by a background processing system (which is the second objective). A further interface would be provided within the system for automatic signaling to the information control system for all updates to the data bases. This interface would enable the information control system to display accurate records from the daily flight schedule.

The second objective would be to provide an efficient *background processing system.* The processing of low-priority or batch-control jobs would be dealt with through the background processing system. This system would be used primarily for producing historical data printouts or jobs that do not require direct interaction with a terminal user. Jobs would be queued either after a request from a terminal user (providing the user has clearance) or automatically at a certain time interval (specified by the system user). Printouts from terminal users normally would be handled serially to simplify any design software required and to minimize costs.

Providing a fault-tolerant *data communications system* would be the third objective. The data communications system deals with the hard-line connections to other airport or external computer systems. Changes to an airport's data bases could be initiated via incoming messages. Outgoing messages from the data bases could be generated automatically or by request from a terminal user. Changes to the data bases and telex-type messages (e.g., via SITA) also would be generated in this manner.

The fourth objective would be to provide an effective *information control system.* To ensure that the total system functions optimally and according to predetermined access criteria and arrangements, the information control system would be required to generate, monitor, and maintain new and updated information.

Finally, the fifth objective would be to provide an effective *information distribution system.* To display information in appropriate formats for specific predetermined uses, the information distribution system would consist of both hardware and software. It could receive information from a wide variety of hosts and from the information control system. This information, stored in paginated form, could be viewed by terminal users via the data base menu. Typically, television monitors and LED and LCD boards are used as display devices for presenting page contents at airports. Because a display device shows the complete contents of one page, any updates would have to be shown in real time on public monitors showing that particular page.

Two methods are available to specify which page must be displayed on a generic console: (a) define a display device as fixed—that is, the console will always show a fixed daily timetable or other related data unless updated by the central data base (e.g., passenger departure monitors), or (b) provide a monitor with a keypad for self-selection of a page of data (e.g., staff keypad monitors at the airport information desk). Both methods can be used together, too.

DEFINITION OF GENERIC MODEL

The scene has been set for revealing the structure of the generic model being proposed, on the basis of the detailed findings of the preceding research. This section describes the structure of information processes and flows following SSADM principles generally and the data flow diagram (DFD) conventions specifically. Figure 2 presents standard DFD notation.

The structure of the proposed model for the generic airport information system (APIS) is shown in Figure 3. The model starts with the nine external entities; the hashed box delineates the system boundary between these entities and APIS functions. Within the system boundary are seven information processing functions: seasonal flight schedule, air traffic control communications, daily flight schedule, flight information display, actual daily flight schedule, flight schedule archive, and flight performance monitoring. Together these constitute this APIS. However, the arrows indicate the main data flows between the external entities and information processing functions and the data flows between information processing functions.

In summary, the main points about this model are (a) the nine external entities are linked to seven information processing functions by 25 separate data flows; (b) the core, or strategic, external entities, as evidenced by the number of separate data flow links, are airline/handling agent systems (4 links) and air traffic control (3 links); (c) the core, or strategic, information processing functions are the flight information display (9 links) and the daily flight schedule (7 links). Taken together, these four activities account for 23 of the 25 data flow links.

Before the model is explored further, it is necessary to explain the seven information processing functions. The role and significance of the seasonal flight schedule consists of the advance program of flights that airlines or their handling agents, or both, plan to operate in the upcoming months—typically these months are winter and

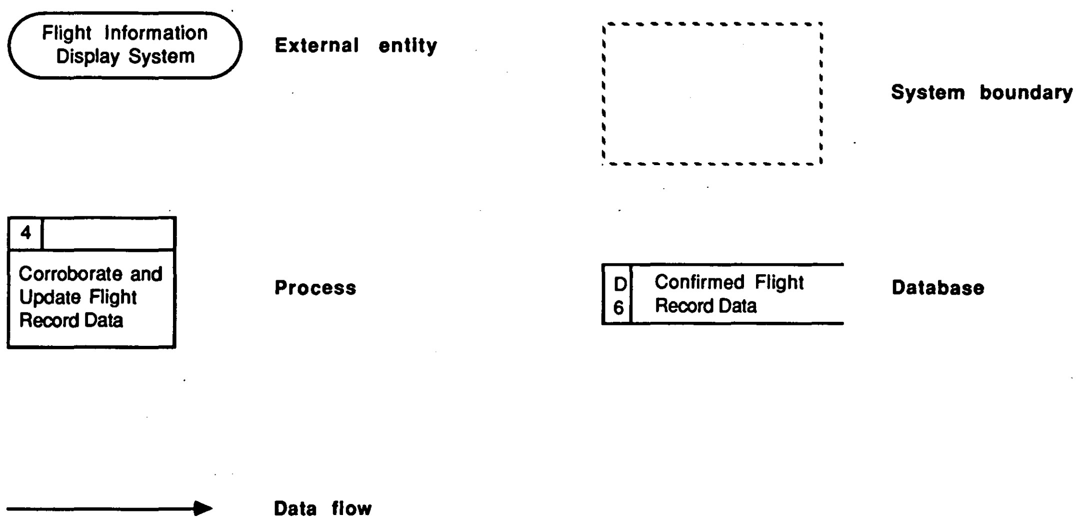

FIGURE 2 Data flow diagramming notation.

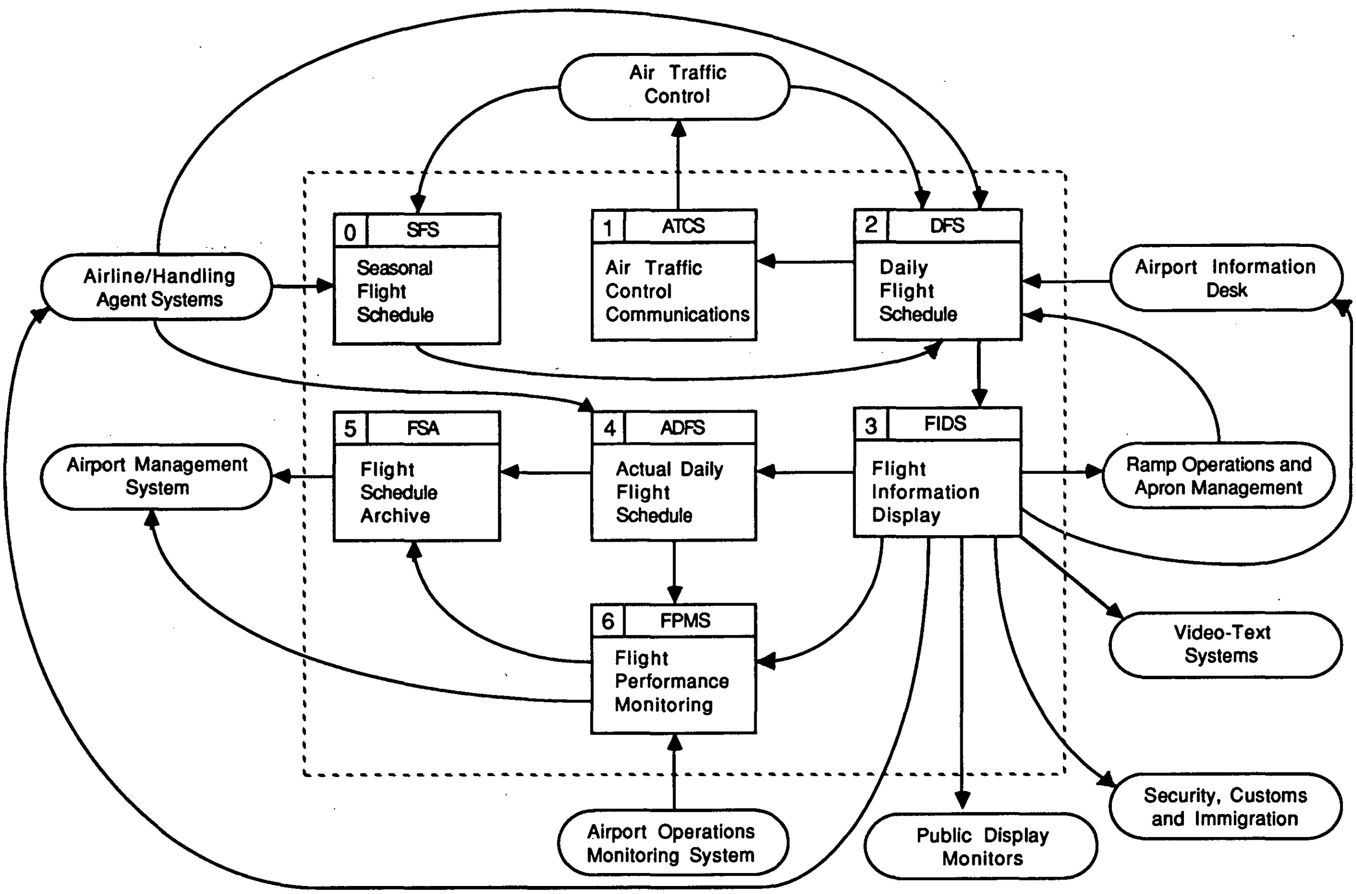

FIGURE 3 APIS: generic model.

summer schedules. Air traffic control communications represents the interface between the control of airspace movements and airport operations; in the context of APIS, it is associated primarily with aircraft takeoffs and landings as well as with apron and taxiway movements.

The daily flight schedule, its prominence described earlier, represents the immediate and current 24-hr period of flights planned and is at the heart of day-to-day airport operations. Links between the daily flight schedule and flight information display are sometimes difficult to disentangle; for example, in many airports both are virtually one and the same (*4*). The flight information display, however, is much more than the system that drives public display monitors in airport terminals: it is the core of real-time information processing at an airport, as the number of data flow links implies.

If the flight information display records and displays data dynamically, the actual daily flight schedule begins the process of information storage and retrieval before the data are archived in the flight schedule archive. As the title implies, the actual daily flight schedule consists of a 24-hr record of the flights that actually took place from 00.01 hr to 24.00 hr. It also provides an "after-the-event" opportunity for airlines or their handling agents, or both, to add data to the information input via the daily flight schedule. At the end of this period, these historic data are transferred to the flight schedule archive for subsequent retrieval and analysis by the external airport management system.

Because if Figure 3 presents the overall structure of APIS, it is now possible to proceed to the next level of system design by examining the data flows within each of the seven information processing functions. Using the same logic and notation, Figures 4 through 9 describe these flows.

Figure 4 begins to unpack the structure of the seasonal flight schedule. In data base management terms, it shows that this function contains two data bases: the planned seasonal flight schedule and the current seasonal flight schedule, the former being updated by a processor called update planned seasonal flight schedule. The output of this process is passed to the daily flight schedule, which is shown in Figure 5. As a consequence, this output becomes the input data to be processed and reconstituted as a third data base, the daily flight schedule, which is then passed to air traffic control via the air traffic control communications black box and the flight information display.

Figure 6 presents the crucial role of the flight information display function and demonstrates that it is much more than an interface between airport operating functions and the display of information on public monitors (*4*). Three data bases are generated following two information processing stages: two data bases, current flight records data and public display data, are generated via a processor called prepare flight records and public display, and the third, video-text data, is generated separately (largely for technical reasons) via the prepare video-text data processor. Two of the data flow outputs become inputs to two further internal information processing functions: the actual daily flight schedule (Figure 7) and flight performance monitoring (Figure 8). In data base management terms, both functions are essentially data merging, data verification, data cor-

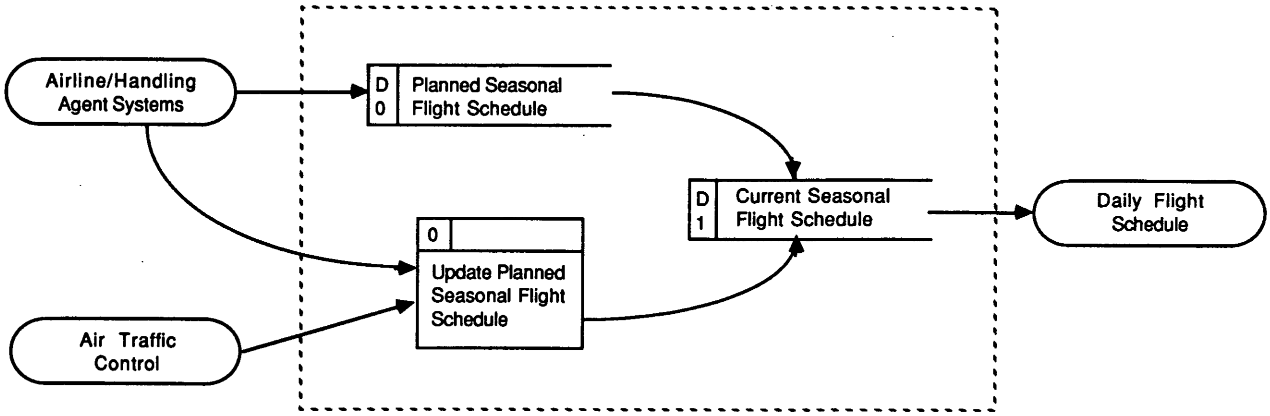

FIGURE 4 **Seasonal flight schedule.**

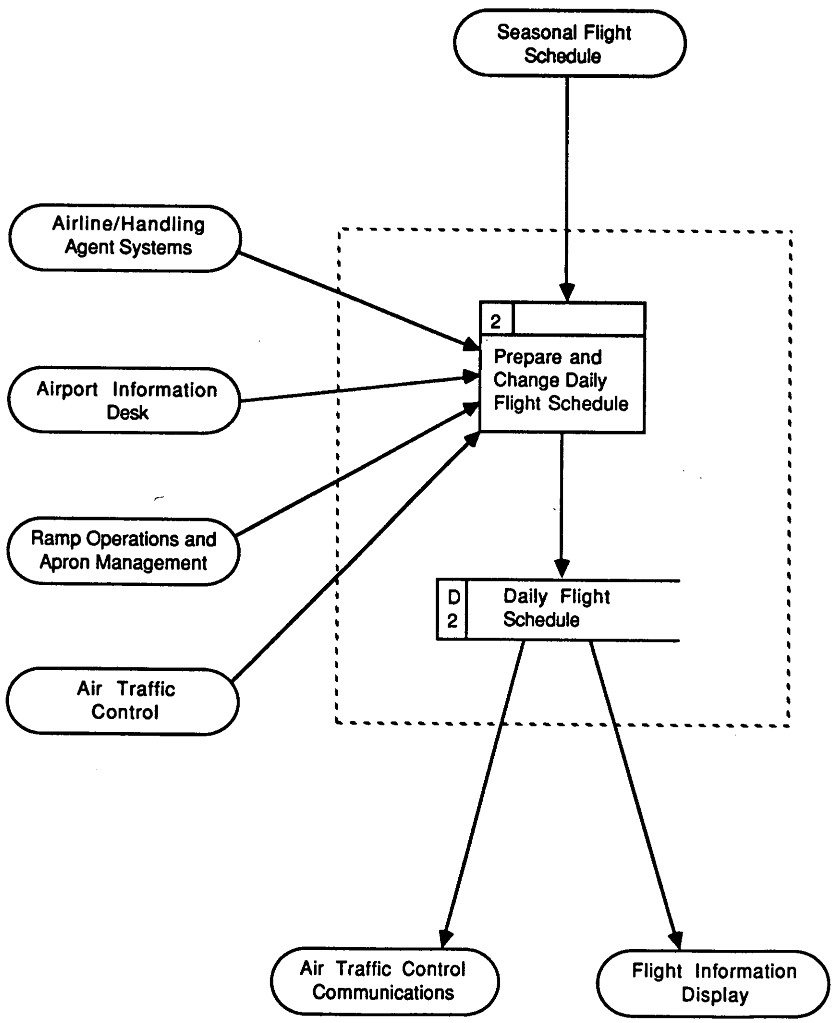

FIGURE 5 **Daily flight schedule.**

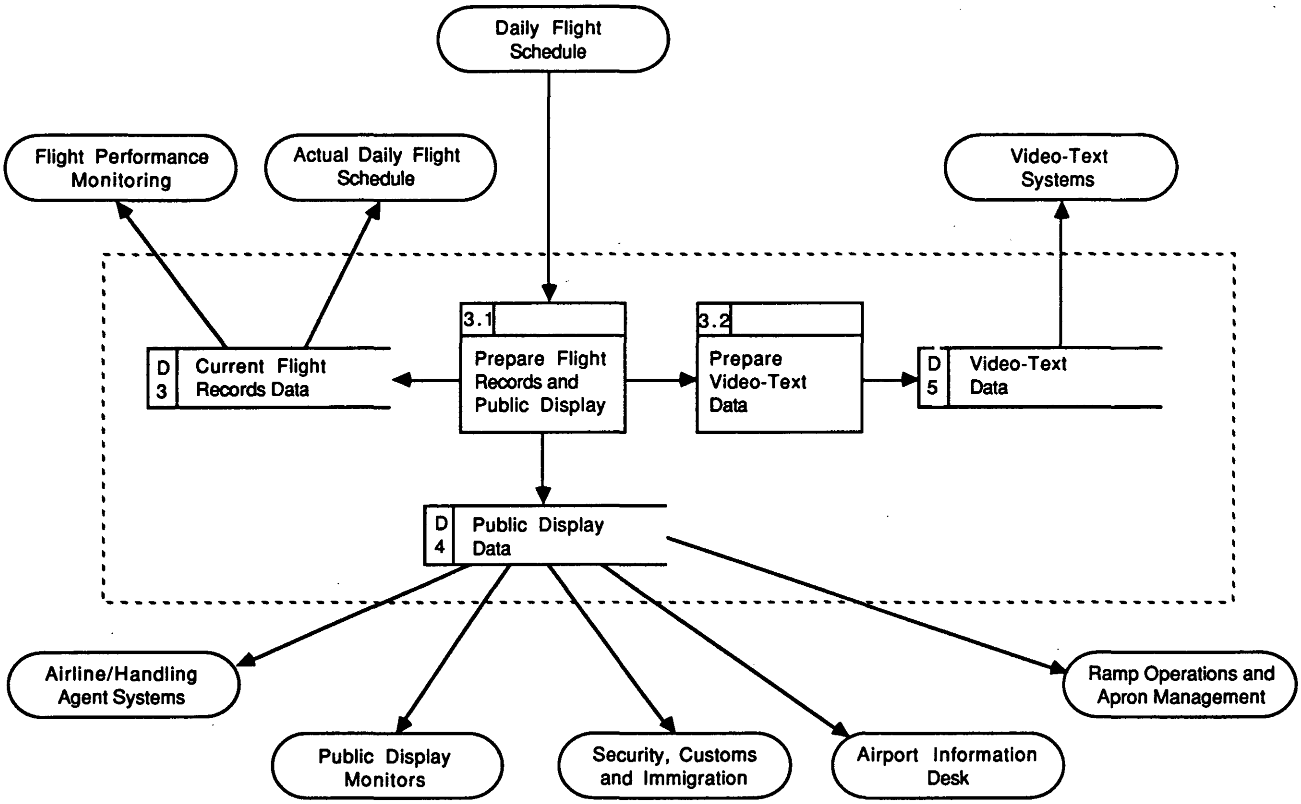

FIGURE 6 Flight information display.

roboration, and data updating activities before data storage and retrieval. The product of the actual daily flight schedule is the data base confirmed flight record data, and that of the flight schedule archive is the flight record archive.

The final data flow diagram for flight performance monitoring (Figure 9) consists of one data base, flight record monitoring data, created by combining data from the external airport operations monitoring system (e.g., an integrated noise monitoring and flight tracking system) with the data merged from the actual daily flight schedule and the flight information display.

Thus having established the structure of the relationships between the key external entities and the internal information

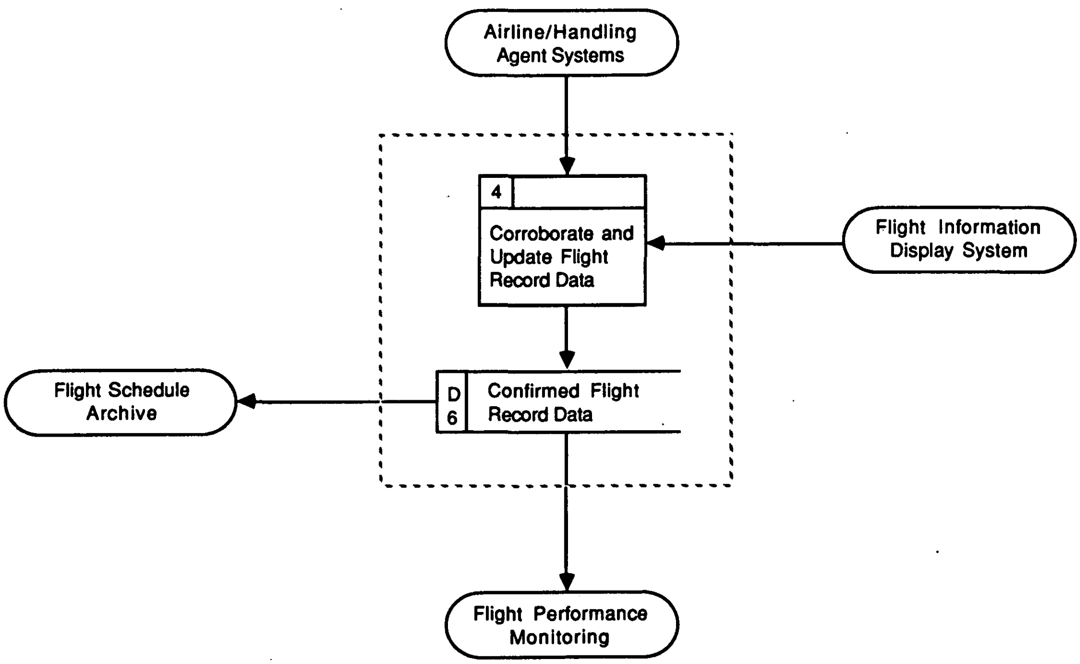

FIGURE 7 Actual daily flight schedule.

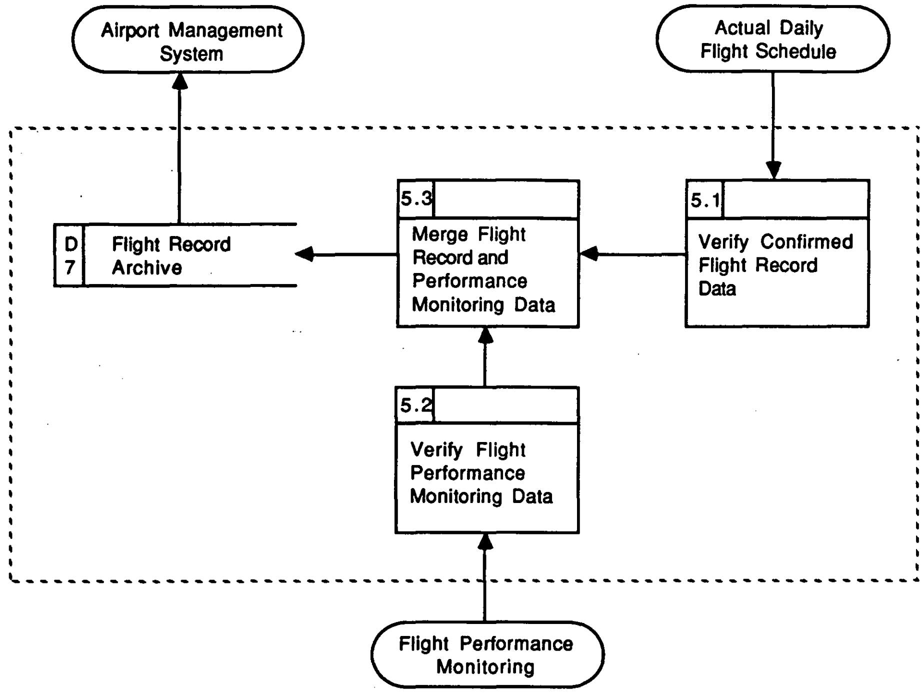

FIGURE 8 Flight schedule archive.

processes as constituting the overall model for APIS (Figure 3), and having identified the data flow relationships within each of the internal information processes (Figures 4 through 9), the next stage would be to identify the internal requirements of and specify the structure for the nine data bases. This stage would come before any attempt to develop software or consider hardware requirements.

CONCLUSIONS

This research has attempted to meet the requirements of the first two of the five stages of an SSADM approach to system development, which was outlined earlier. What has been presented should be seen as the first steps toward developing software for an APIS configu-

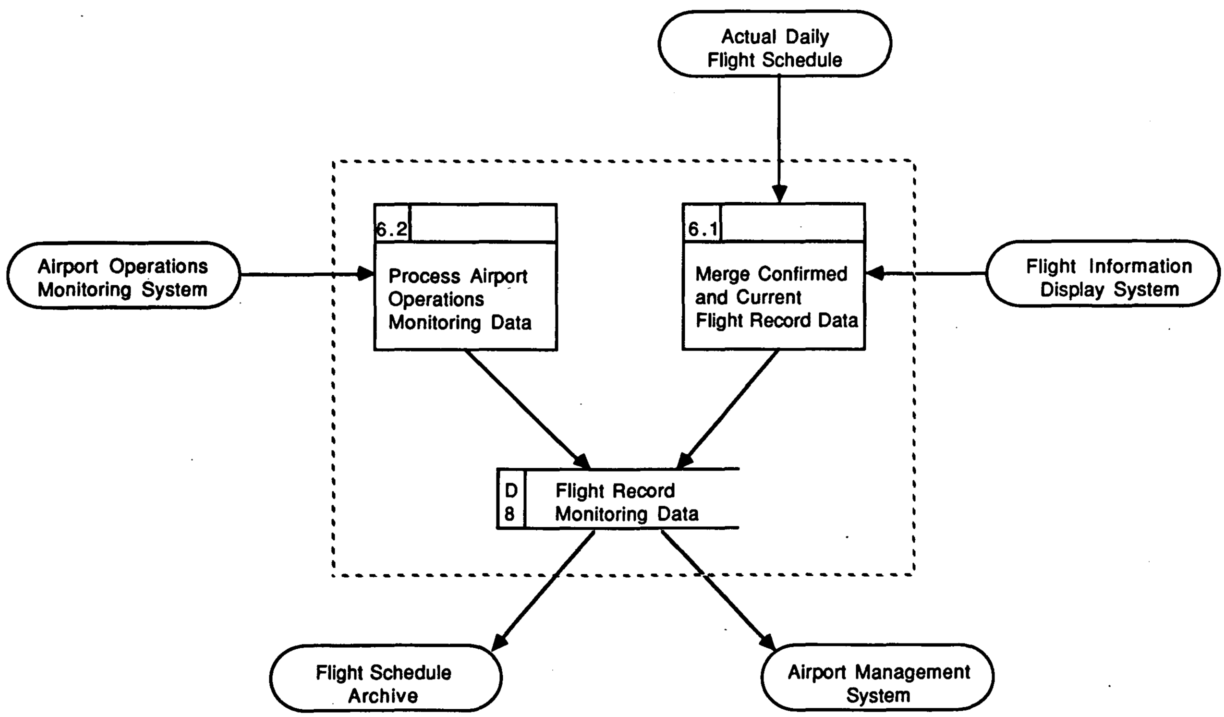

FIGURE 9 Flight performance monitoring.

ration. The proposed APIS is generic because, in principle, it should apply to any and all airports; it has been based on tracking flows of information between users and translating those flows into a systematic structure that does not necessarily conform to existing organizational boundaries or corporate functions. It demonstrates an approach to thinking about information management in data base management terms, which is independent of information "owners" and IT professionals.

ACKNOWLEDGMENTS

The research in this paper, and reported in full elsewhere (*5*), relied on the active collaboration of a large number of individuals and organizations. Needless to say, the paper reflects the views of the authors rather than those who collaborated in its production.

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Maximizing Use of Airport Operations Data: Honolulu International Airport

PANOS D. PREVEDOUROS AND COSTANTINOS S. PAPACOSTAS

Tapping existing data sources that often are scattered among components of the same organization and incrementally enhancing existing data bases and data collection practices within realistic constraints compose a prudent approach to improvement. A recent effort to maximize the use of existing operations data at the Honolulu International Airport is described, and the wealth of analytical capabilities that can be unleashed by taking advantage of routinely collected data that had been used minimally in the past is displayed. Analysis procedures and sample output are given for passenger flow, cargo and mail traffic, flight arrivals and departures, diurnal distribution of operations, load factors, aircraft types, arrival and departure delays, aircraft ground time, and aircraft returns due to mechanical problems. An innovative way to profile airline operations is also presented.

The availability of comprehensive, consistent, accurate, and accessible data is a prerequisite to high-quality analyses and performance evaluations of transportation facilities to support informed policies. But, as several studies have shown (*1–6*), no data base can meet this ideal to the satisfaction of all its potential users. No data base can satisfy all users for many reasons, particularly because of resource and technological limitations, institutional barriers, and constantly changing conditions and requirements. Nevertheless, developments in computer technology and data management methods offer opportunities for significant improvements. Tapping existing data sources that often are scattered within the same organization and incrementally enhancing existing data bases and data collection practices within realistic constraints compose a prudent approach to improvement.

Passenger travel to and from Hawaii depends almost exclusively on the air transportation system. The same is true for travel between the islands that make up the state. It is not mere coincidence that the arrival of the first jet carrier in 1959 marked the beginning of unparalleled economic growth that transformed the state's economy from agriculture to tourism. The now mature visitor industry faces severe global competition, and its success depends partly on the efficiency of the state's airports.

Hawaii's airport system is unique in that the state government owns and operates all public airports on each of the major islands. Located on the island of Oahu, which has 80 percent of the state's population, Honolulu International Airport (HIA) "is the major aviation gateway for the State of Hawaii. It is presently the only airport in the State accommodating international flights, and is the primary hub for overseas domestic and interisland flights" (*7*). Its facilities accommodate all types of aircraft operations, including commuter/air taxi, general aviation, and military flights. Depending on the indicator used (e.g., annual aircraft operations, passenger demand), HIA has been ranked in recent years as the 12th to 15th busiest airport in the country.

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Responsibilities for operating and directing the statewide system are centralized at the Airports Division of the Hawaii Department of Transportation (DOT). The administration of the division recognizes the importance of the airport system to the state's economy and is fully aware of the central role that high-quality data play in the system's performance. As a result, the division has enhanced its information base and its analytical capabilities. It recently implemented an innovative computer-administered method to conduct airport-user satisfaction surveys and investigated the comparability of the data obtained via this method with those data obtained using traditional techniques (*8*). The division also expressed interest in regularly compiling detailed statistical reports of the aircraft operations and passenger flows handled by the airports under its control. Toward this end, it awarded the authors a project to identify the major sources of data collected within the division, computerize hard-copy information, perform a basic analysis of the data, and undertake further analyses made possible through the integrated data sets obtained (*9*).

DATA SOURCES AND NEEDS

The major types of data that are maintained by various units of the division, current uses of the data, perceived limitations, and expressed staff desires for better data use were identified. Two major and several supplementary data sources were identified, evaluated, and used.

The major long-standing source of passenger, cargo, and mail flows handled at the six major state-owned airports is a monthly air traffic summary submitted by each airline to the division and to the Hawaii Visitors Bureau (HVB), an organization charged with promoting tourism. Designed jointly by the airlines and these two organizations, the report form contains monthly summaries showing the volumes of enplaning and deplaning passengers and the amounts of cargo and mail transported between the major state airports and eight regions of the world. The division processes the hard-copy reports to produce monthly, quarterly, and annual reports for each airport. These data go back to 1960, with 5-year summaries before 1970 and annual reports thereafter. Although conversion from manual to computer-based spreadsheet procedures has improved reporting efficiency, airport staff expressed a need to enhance the tabular format of the reports and to incorporate graphics to aid understanding and interpretation of trends over time.

The major source of disaggregate aircraft flow data was the terminal ramp control tower. These data primarily are used for real-time operations, such as the assignment of gates and baggage claim areas, and displaying and disseminating schedule information to the public. Although the direct need for this voluminous information is transitory, permanent records of otherwise unavailable data are produced in the process on hard-copy logs. The recorded information for each arriving flight includes the date; airline and flight number; an abbreviated form of the aircraft tag number; turnaround flight; aircraft type; origin of flight segment ending at HIA; scheduled, estimated, and actual times of arrival; and assigned/used gate. Similar data are recorded for each departing flight.

For arrivals, the turnaround flight designates the departing flight to which the arriving aircraft is assigned, whereas for departures it represents the arriving flight served by the departing aircraft. The two turnaround flights can be linked to provide information on aircraft use, flight characteristics (e.g., originating at HIA, terminating at HIA, or continuing), and gate use. The size of this data base and the hard-copy format in which it is maintained are two barriers to routine use of the ramp control data for purposes other than real-time scheduling. At HIA the resulting computer file for each month approaches the limits of common spreadsheet programs running on 386-based personal computers. As for the storage medium, hard-copy forms with preprinted information on scheduled operations are computer-generated daily. Entries in the remaining fields (e.g., aircraft, actual time of arrival) and information on unscheduled flights are entered manually on the logs as the day progresses.

Supplementary data sources include confidential monthly landing use charge listings, which are maintained by the Fiscal Office and classified by airline and by airport, and the recently computerized U.S. Customs and Immigration data for each arriving international flight. These data are the only source that provide a breakdown of the characteristics of all arriving passengers on each flight. The categories employed obviously are relevant to the differing processing requirements and related facility needs for citizens and noncitizens entering the country.

DATA PROCESSING, ANALYSIS, AND REPORTING

The data from the previous sources were used, either singly or combined, to compile many statistical reports relating to airports, airlines, and the overall airport system. The integrated data sets were processed further using SPSS/PC+ to quantify a variety of performance indicators and to analyze their changes over time. The main data sets used included the monthly air traffic summaries dating back to 1960 and the disaggregate ramp control data for each January from 1989 through 1992. The confidentiality of the supplementary data was protected by avoiding direct detailed reporting and by embedding only aggregated subsets in composite indicators.

The following sections illustrate both the types of analyses employed and the wealth of useful information that can be obtained by integrating a small number of already existing data sets.

Traffic Flows

The most disaggregate level to which volumes of passengers and cargo could be reported consisted of monthly enplaning and deplaning volumes, by airline and by points of interchange—that is, between individual airports within the state at one end and several subregions of the world at the other. In land-based terminology, the reported interchanges represent unlinked trips, not trips between ultimate origins and ultimate destinations. Nonetheless, the availability of this type of information in automated form can provide quick answers to many policy- and operations-related questions that would be very difficult and expensive to obtain otherwise in a timely fashion. Moreover, because a centralized data base is maintained, aggregating passenger, cargo, and mail flows up to the statewide level and for any period over a month is relatively easy.

Figure 1 presents all annual aircraft operations at HIA by type, that is, air carrier, air taxi, general aviation, and military. This information is subject to further interpretation and association with underlying causes and trends (e.g., increased military carrier activity during the Vietnam War era and declines in civil aviation during downturns in the national economy). Combined with other data, such as passenger flows by sector, the data in the graph reflect changes in technology (i.e., the introduction of larger aircraft) and other factors.

Flight Arrivals and Departures

The segment origins and destinations of overseas flights to HIA are presented in Table 1, which reveals the interchange patterns for cities with four or more monthly flights. A fairly strong diagonal element is observed, which reflects round trips. Two easily distinguishable columns and rows correspond to Los Angeles and San Francisco as origins and destinations of flights. Similar charts were developed for each of the airlines that provide service to Hawaii; these charts clearly demonstrate the dominance of United Airlines in the overseas Hawaiian market.

The pattern shown does not reflect the ultimate origins of arriving passengers or aircraft, particularly those on domestic flights, largely because of the hub-and-spoke networks that evolved in the United States following the Airline Deregulation Act of 1978. Thus, travelers from the East Coast of the United States are likely to be

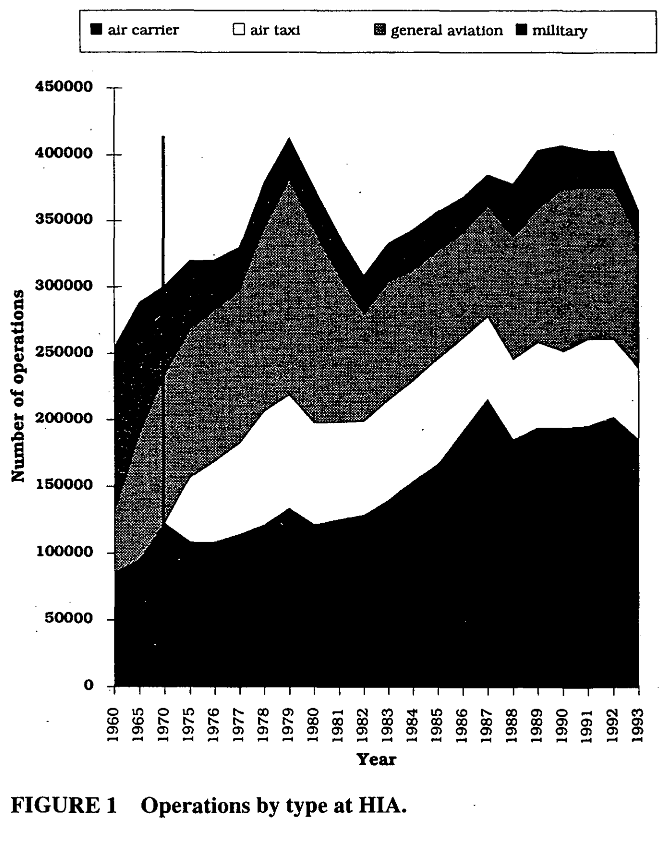


FIGURE 1 Operations by type at HIA.

TABLE 1 Origins and Destinations of Flights to and from HIA (averages from each January from 1989 to 1992)

ORIGIN \ DESTINATION	ATLANTA	AUKLAND	BALI	BIAK	CAIRNS	CHICAGO	DALLAS	DENVER	FUKUOKA	GUAM	HONG KONG	KAHULUI	KONA KEAHOLE	KUALA LUMPUR	LAS VEGAS	LIHUE	LOS ANGELES	MANILA	MINNEAPOLIS	NAGOYA	NANDI FIJI	NEW YORK	OAKLAND	ONTARIO	OSAKA	PAPEETE	PHOENIX	SAN DIEGO	SAN FRANCISCO	SAN JOSE	SEATTLE	SEOUL	ST. LOUIS	SYDNEY	TAIPEI	TOKYO	TRAVIS AFB	TORONTO	VANCOUVER
ATLANTA	9						13																																
AUKLAND		6					4										33												10							15			7
BALI																	9																						
BIAK																	8																						
CAIRNS																	4																						
CALGARY																																							8
CHICAGO						41		5				22					4												5										
DALLAS F.W.	14	4				4	24					28					12																	7					
DENVER								10				8					8												5										
EDMONTON																																							4
FUKUOKA																	7																						
GUAM										34							15												6								6		
HOUSTON																																				7			
KAHULUI						30	29					18					95											5	12										
KONA-KEAHOLE						7											21																						
KUALA LUMPUR																	4																						
LAS VEGAS																											7												
LIHUE																													28										
LOS ANGELES		42	9	8	5	11	14		7	19		88	27	4		4	194	31			44							25	74		11	17		15	26	16			
MANILA																	24												24										
MINNEAPOLIS																			5																				
NAGOYA																				14							4									11			
NANDI, FIJI																	23																						5
NEW YORK																																6							
OAKLAND																							23																
ONTARIO, CA																								38															
OSAKA																									26				6							66			
PAGO PAGO																										4													
PHOENIX															8					4							16												
SAN DIEGO																	29																						
SAN FRANCISCO		17				7		10			10	11				26	85	20											134		6			32		10			
SAN JOSE																														5									
SEATTLE/TAK.																	8												5		72								
SEOUL																	18					5										31				7			
ST. LOUIS																																	30						
SYDNEY							7										17												30									8	
TAIPEI																	18																						
TOKYO																	21			12					68				17			6				239			
TRAVIS AFB										8																													
VANCOUVER		6			6																8																		51

consolidated at major airports such as Chicago, Denver, Los Angeles, and San Francisco and then flown to Hawaii. Similar patterns apply to several Asian countries. For example, there are no direct flights from the People's Republic of China to Honolulu, and most flights by China Airlines are routed through Tokyo. Complementary sources of data that can supply partial answers to this pattern include the International Air Transport Association's origin-destination passenger and freight statistics, the Air Transport Association's annual survey of airline passengers, and the *Passenger Origination and Destination Survey*, which is based on a 10 percent sampling of airline tickets and filed by certificated U.S. carriers providing scheduled service. For westbound (i.e., from North and South America) visitors to Hawaii, a voluntary survey is distributed by HVB to all passengers on inbound flights.

Diurnal Distribution of Operations

Figure 2 shows the pattern of the average number of daily aircraft operations by time of day for a selected month. This profile includes data for major and regional air carriers only; the data are disaggregated into overseas arrivals, overseas departures, and total operations by each of the two main inter-island carriers. The differences in the profiles of overseas arrivals and departures are influenced partly by the long distances and time differences between Hawaii and the other end of the flights included in the graph as well as by restrictions and curfews imposed at other airports. As demonstrated later in this paper, the operations profiles of individual airlines can be shown separately.

Load Factors

Given the readily available data, approximations of aircraft load factors were possible only for international flights that are unlikely to carry transit passengers (screened from the ramp control data set) and for which flight-specific passenger data are available from U.S. Customs and Immigration. The types of aircraft used for the selected flights also were identified from the ramp control data, but the exact seating configuration of each aircraft was not known; approximate seating capacities were obtained from the *Official Airline Guide*. Analysis of the estimated load factors (Figure 3) by geographic region and airline reveals that airlines from Japan, Korea, and China achieve a high average load factor (weighted by the total number of flights), 75 percent, as do most U.S. airlines, 79 percent. Airlines from Canada display a large load factor variation, with an average of 63 percent, whereas airlines from other Pacific Ocean countries show the lowest average, 41 percent. A possible explanation of the last finding is that these airlines may be flying combined passenger/cargo aircraft with much lower seating capacity.

An interesting, if not unexpected, finding is the trend in the average number of passengers per aircraft over time. The number of pas-

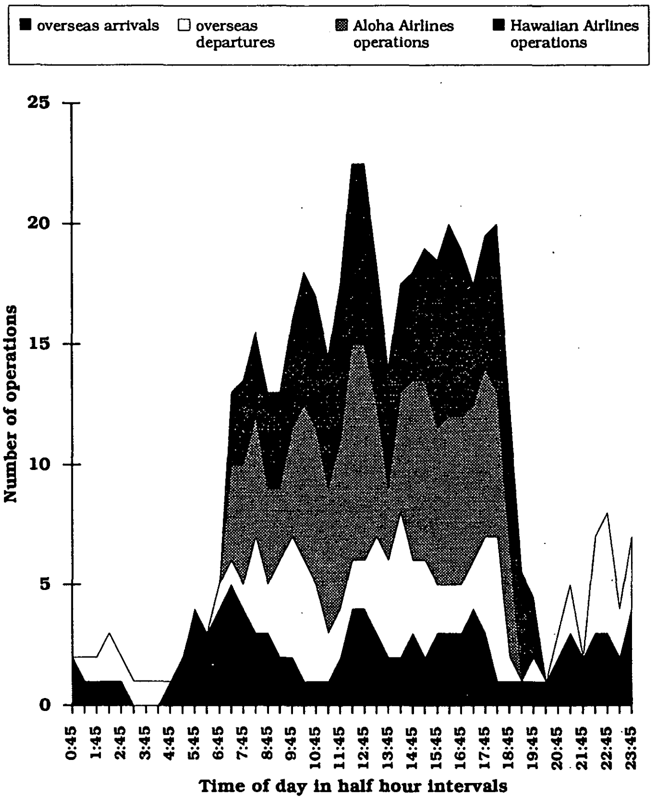


FIGURE 2 Average daily operations in January 1991 at HIA.

sengers per aircraft showed a sharp reversal, steadily increasing since the passage of the Airline Deregulation Act of 1978. This finding supports the contention of those who argue that market competition following deregulation has resulted in increased economic efficiencies.

Aircraft Types

Figure 4 presents the 4-year trends in the types of aircraft used by overseas carriers. The B747 and the DC-10 are the overwhelming favorites. However, a mild decline in the share of jumbo-class aircraft and a concomitant increase in the share of large but more economical two-engine aircraft (such as the B767) are also evident. The response of the air carriers to the peak demand experienced during 1990 is also apparent: there was a noticeable reduction in flights using the DC-10, which has approximately 275 seats, in favor of the B747, which has approximately 350 seats.

Arrival and Departure Delays and Aircraft Ground Time

Arrival and departure delays are defined herein as the differences between actual and scheduled operations. This definition is consistent with the manner in which the term is defined in the U.S. DOT's *Air Travel Consumer Report*. As explained, "although these data are useful to consumers insofar as they encourage carriers to publish realistic schedules, they do not provide an accurate gauge of delays because carriers have built many of these delays into their schedules" (*4*). The monthly *Air Travel Consumer Report* contains on-time performance data on domestic flights delayed more than 15

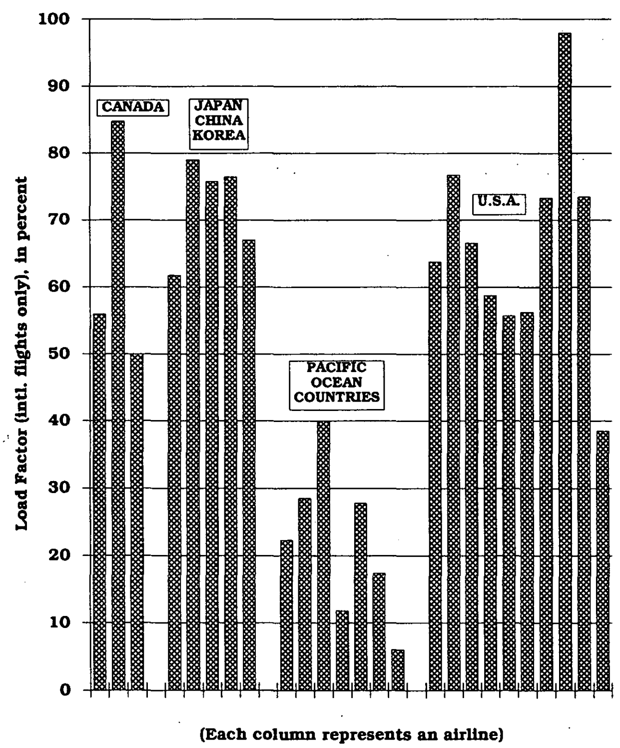


FIGURE 3 Airline load factors.

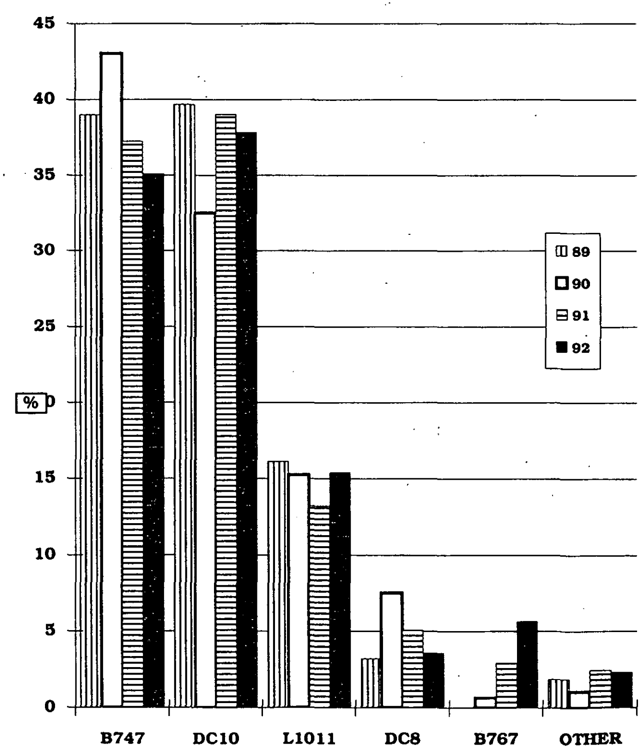
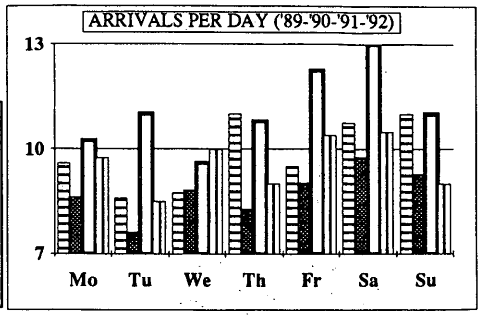


FIGURE 4 Share of aircraft types (overseas arrivals).

PACIFIC AIRWAYS

NOTE: ALL DATA ARE MONTHLY UNLESS OTHERWISE SPECIFIED

NUMBER OF FLIGHTS FROM LISTED CITIES/PLACES				
ORIGINS	'89	'90	'91	'92
LOS ANGELES	93	88	88	65
SAN FRANCISCO	59	60	54	54
GUAM	30	27	35	50
HOUSTON	0	0	30	0
SYDNEY	32	31	30	31
AUCKLAND, NZ	28	30	29	31
TOKYO	1	0	28	31
MANILA	9	8	14	0



VOLUMES	'89	'90	'91	'92
O/S H.I.A./TR	136,187	130,499	141,485	122,387
O/S to N/I	0	0	0	0
I/I PASS.	0	0	0	0
O/S CARGO	8,202,112	7,594,304	9,443,251	8,513,866
O/S to N/I	0	0	0	0
I/I CARGO	0	0	0	0
O/S MAIL	213,082	392,920	1,414,941	1,289,998
O/S to N/I	0	0	0	0
I/I MAIL	0	0	0	0
LAND. FEES	$98,167	$92,558	$115,138	$93,214

Note: O/S/=overseas, TR=transit, I/I=interisland, N/I=neighbor islands]

HIA MARKET SHARES (%)				
O/S PASSENGERS	'89	'90	'91	'92
IN+OUT+TRANSIT	10.9	10.5	11.0	10.2
I/I PASSENGERS	0.0	0.0	0.0	0.0
O/S CARGO	18.8	18.3	20.4	19.2
I/I CARGO	0.0	0.0	0.0	0.0
O/S MAIL	4.7	7.5	24.8	19.7
I/I MAIL	0.0	0.0	0.0	0.0

STATEWIDE MARKET SHARES (%)				
PASSENGERS	6.6	6.3	7.2	6.1
CARGO	14.2	13.5	16.4	13.6
MAIL	3.5	5.6	18.5	15.1
LANDING FEES	8.1	7.6	9.4	6.9

ON TIME PERFORMANCE				
[minutes of delay]	'89	'90	'91	'92
ARRIVAL	2.7	3.2	1.9	8.7
DEPARTURE	16.4	22.0	22.3	4.6

ARRIVALS	'89	'90	'91	'92
(flights/mo)	302	270	342	298

		ARRIVALS	SEATS*
AIRCRAFT ('91)	DC-10	177	296
(*=approximation)	B747	165	353

LOAD FACTOR : 63.9%

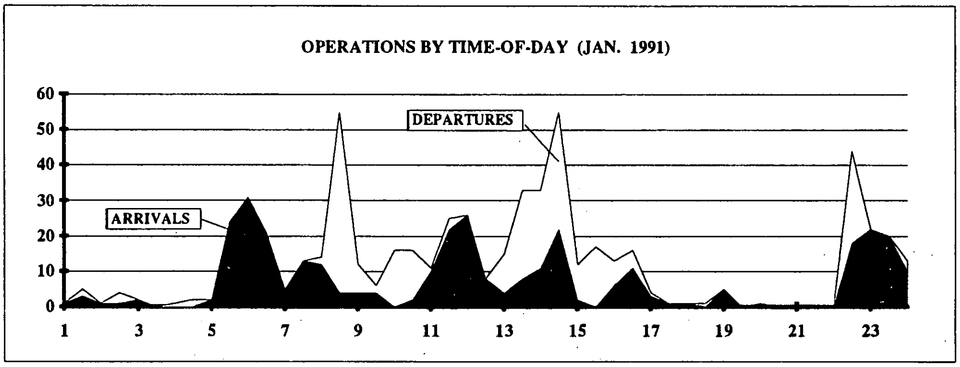


FIGURE 5 Sample airline profile.

min, as reported by the 12 largest air carriers. An alternative definition of delay is used by FAA in two systems: the Air Traffic Operations System, which contains reports submitted by air traffic controllers relative to the total flights delayed more than 15 min, and the Standardized Delay Reporting System, which, since Eastern Airline's demise in 1991, is drawn from reports submitted by two major carriers. The alternative definition of delay is measured against "optimal" rather than scheduled times.

The distribution of arrival delays was compiled from the HIA ramp control data set, which has 10,703 cases for which the actual arrival and departure times of individual aircraft are available. From the 4 months analyzed, 4.6 percent of the flights arrived more than 15 min earlier than scheduled, 86.7 percent arrived within 15 min of the scheduled arrival times, and only 8.7 percent were delayed more than 15 min. A similar analysis revealed that about 10 percent of the aircraft stay in Honolulu for 1 hr or less, 47 percent for up to 2 hr, 19 percent for 3 to 5 hr, and 24 percent for more than 5 hr.

Mechanical Problems

Ramp control data indicate that older aircraft, such as the DC-8, experience by far the highest number of returns. All other major types of aircraft flown to Honolulu have excellent records, given that fewer than 0.5 percent of the departed flights return because of equipment problems. The B747 has improved from 1989 to 1992, whereas the opposite is true for the DC-10. The reason may be related to the age of the aircraft. The B747 is still being produced in large numbers, which means that several aircraft serving Honolulu are fairly new. In contrast, production of the DC-10 has been phased out, and the airplane has been replaced by the MD-11.

Airline Profiles

Integration of the data sets permitted the creation of two-page profiles for each of the 25 air carriers serving HIA. The first page of these summaries (Figure 5) presents the following characteristics:

- Origins of flight segments ending in Honolulu;
- Overseas, inter-island, and in-transit volumes of passengers, cargo, and mail;
- Average monthly number of arrivals;
- HIA and statewide market shares;
- On-time performance;
- Types of aircraft used and average load factors; and
- Average number of arrivals and departures by time of day.

The data in Figure 5 are real; however, the airline's name is fictitious. The second page of the summary airline profiles presents origin and destination tables in the same format as in Table 1.

CONCLUSIONS

A number of national panels assembled in recent years to examine data resources and data requirements to support national transportation decision making have deplored the lack of data—even for aviation, the most data-rich of all modes. In many cases the problem lies in the difficulty of access to existing data rather than a dearth of data. Fixing this problem and proceeding incrementally from there appear to be the highest priority requirements.

This paper describes a project to tap existing data sets relating to the operation of HIA. The project provided an improved way to perform old tasks and a wealth of statistics and special analyses to support decision making at all levels. By supplying useful information (e.g., delay distributions), the project also facilitated newer activities within the Airports Division, such as airside and landside simulation that was almost at a standstill because of insufficient data.

Previously, most routinely used data sets were maintained at a coarse level of aggregation. With recent improvements in computer technology, such aggregation should no longer be the case, and reasonable levels of data disaggregation are possible. With improved data management methods, analysts are freer to take advantage of the rich disaggregate data to perform a multitude of special-purpose analyses continually (i.e., gate allocation and use, internal passenger traffic, baggage handling characteristics, time-of-day profiles, identification of peaking characteristics, etc.). Such detailed information would help fine-tune day-to-day operations, plan for improvements, and produce both macroscopic and detailed forecasts.

Behind these opportunities lurks a danger: inundation by data, or, as Schmitt stated, "Can we cope with sudden floods of new data, as happened when we started collecting flight delay information and swamped DOT with a sudden staggering flow of numbers to be transformed into useful information" (*1*). Part of the answer is not to let ambitious data collection plans outpace the ability to process and, more importantly, use these data for the purposes they are collected in the first place. These enhancements can be accomplished with a modest increase in staff positions, at a cost that is far outweighed by the benefits.

ACKNOWLEDGMENTS

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Role of Door-to-Door Vans in Airport Ground Transportation

ERIC MOHR AND GEOFFREY D. GOSLING

The characteristics of door-to-door van service in the airport ground transportation system are analyzed. The evolution of airport ground transport is traced; the market niche of door-to-door van service is delineated; and air passenger characteristics favoring door-to-door modes in general and door-to-door vans in particular are reviewed. A detailed intermodal comparison of vehicle kilometers (vehicle miles), person minutes, and user cost for air-traveling parties of various sizes using the six airport ground transport modes is presented. Management issues facing door-to-door van service managers are discussed, and information needs of the industry and future research needs are indicated.

Airports are among the largest generators of people and goods traffic in metropolitan areas. Airport ground traffic is dispersed throughout most of the day, 7 days a week; it originates from, or is destined to, points throughout the metropolitan area. Because the movement of people to and from airports is so diffused in time and space, this traffic is carried mainly in low-occupancy vehicles, thus imposing a significant traffic load on roadways, particularly near the airport. As traffic volumes begin to cause congestion, consolidating person traffic into fewer vehicles becomes especially important.

Of the six major forms of airport ground transportation that handle passenger movement, three use automobiles mainly—self-driver, car passengers, and taxi—and three use larger vehicles—scheduled airport buses, transit (rail or bus), and door-to-door (D/D) vans.

This paper examines the factors affecting the use of D/D vans, the newest airport ground transport mode, and addresses planning and policy questions raised by the growth of that mode. It analyzes the general characteristics of the D/D van market and discusses operational problems. The paper also compares the performance of typical D/D van service with the more traditional modes. Finally, the paper discusses some management issues for both operators and airports in providing D/D van service.

D/D VAN SERVICE

During the past two decades, D/D van service has become available at major airports in the United States. It is now spreading to medium-sized airports and is likely to grow substantially in coming years. With this growth has come a number of problems at some airports, including proliferation of operators, increased curbfront congestion, and wide variation in the quality of service (*1*).

For the inbound trip to the airport, a passenger calls a D/D van carrier in advance to be picked up by a van (typically a van has a 7- to 11-person capacity) at the place requested at an agreed time. The passenger's origin may be any point within the carrier's service area, such as a private residence, hotel, office, factory, or military base. Other passengers may be aboard already or be picked up on the way. The van then takes the group to the airport for passenger drop-off at the respective airline terminals.

On the outbound trip from the airport, the pattern is reversed. That is, the van picks up passengers bound for the same general area at the curb of various airport terminals. Some passengers may have advance reservations; many will be walk-ups. The van takes the group to the destination area, drops each passenger at his or her specific destination, and, after the last drop, repeats the next cycle.

In the spectrum of transportation operations, D/D van service can be classified as a demand-responsive, shared-ride operation: inbound, it follows a few-to-one trip pattern; outbound, a one-to-few trip pattern. Both route and schedule are flexible.

EVOLUTION OF AIRPORT GROUND TRANSPORTATION

Travel Patterns

Early airport ground transport typically involved trips between the central city and an airport on the outskirts. This trip pattern has undergone major changes on both ends. Metropolitan areas have grown in both population and extent; residences, commercial and industrial concentrations, convention facilities, and other activity centers are dispersed throughout the area. The role of the central business district as the end of the trip for air passengers has been reduced. Air passenger origins and destinations have become more widely scattered and more difficult to serve by a fixed route operation.

Major airports have grown from simple landing strips with small terminal buildings into large multiterminal complexes that require several stops by ground transport carriers and often operate their own internal transport systems, such as bus or rail shuttles or moving walkways. Satellite cities with hotels, convention centers, and industrial parks have developed around airports. Many large metropolitan areas now have more than one airport, further adding to the dispersal and complexity of ground transport.

Modal Characteristics

In the early decades of aviation, airport ground travel was primarily by private car or taxi. Air passengers generally had ready access to either one: both provided convenient, almost door-to-aircraft transportation.

As passenger volumes grew, a specialized form of ground transport emerged: the airport "limousine," typically shuttling passen-

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gers between a major downtown hotel and the airport. The name reflected both the type of vehicle used and the connotation of luxury transportation associated with early aviation. As traffic volumes grew, the limousine was replaced by the airport bus, often a 40- to 50-passenger vehicle serving several major hotels or a downtown terminal. (Limousines in the original sense still exist as luxury charter vehicles at many major airports; they are not considered a major ground transport mode and thus are not discussed further in this paper.) Air passengers, except those passengers staying at one of the hotels served directly, need to arrange for their own transportation between an airport bus stop and the actual trip end.

Increasingly, metropolitan areas have attempted to integrate the airport into their transit network in order to serve air passengers as well as the thousands of airport workers and visitors. A number of airports, both in the United States and abroad, not only are served by transit bus routes but also incorporate stations of the rapid transit system or regional rail network.

Private cars are still the dominant mode of airport ground transportation. For San Francisco International Airport, an airport with a high proportion of visitors having no access to a private car, a recent survey showed that 51 percent of air passengers used private cars to reach the airport (*2*). At many airports, the ratio is even higher.

Over time, the handling of private cars at the airport has changed. At most major airports, air passengers no longer can park close to the aircraft or even the check-in counter; instead they must use the airport garage or an outlying parking lot and carry or wheel their baggage to a bus or rail shuttle or combine walking, moving walkways, escalators, or elevators to cover a considerable distance. Those passengers using rental cars may park even farther away; however, they usually are transported by the rental company's shuttle van to their airport terminal door.

Thus, most air passengers using airport buses, public transit, or rental cars or parking private vehicles at the airport experience multiseat rides involving one or more transfers to go to and from airport terminals. The air passenger using a taxi or being dropped off or picked up at the airport by a household member, friend, or business associate receives single-seat D/D service, but at a price: the taxi fare or the roundtrip time and cost of the person driving the vehicle in the unaccompanied direction.

By providing direct D/D service at a time that the traveler has chosen, ground transport by taxi or private vehicle offers a significantly higher level of service, although generally at a higher cost, than transit or airport bus. It was to be expected that a form of transport intermediate in both service and cost would emerge. This new form is the niche of the airport van, offering D/D service on a shared-ride basis. D/D vans now have a significant share of ground transport at many major airports. A 1992 survey at San Francisco International Airport indicated a 13 percent share of air passenger trips to the airport, greater than any other mode except private car (*2*).

Table 1 gives a summary of the characteristics of the various ground transport modes, viewed from the perspective of the trip inbound to the airport; symmetrical information would apply to the outbound trip.

CHARACTERISTICS OF D/D VAN MARKETS

To understand the role of D/D van service in the context of airport ground transport, it is essential to first understand the factors that affect the use of the mode.

TABLE 1 Airport Ground Transport Modes: Key Characteristics of Inbound Trips

Characteristic	Airport Ground Transport Mode					
	Transit	Airport Bus	**D/D Van**	Taxi	Car Psgr (a)	Self Driver
Trip Configuration						
Door-to-Door Service	no	no (b)	**yes**	yes	yes	no
Type of Line Haul Ride	shared	shared	**shared**	exclusive	exclusive	exclusive
Pickup/Access Trip (c)	yes	yes	**yes**	yes	no (d)	no
Trip Components						
Pickup at Origin Door	no	no	**yes**	yes	yes	yes
Transfer(s) Required	yes	yes	**no**	no	no	yes (e)
Delivery at Airport Door	no (f)	yes (g)	**yes**	yes	yes	no
Parking Required	no	no	**no**	no	no	yes
Other						
For-hire Carrier	yes	yes	**yes**	yes	no	no
Fare Level	low	low intermediate	**intermediate**	high	n/a	n/a

(a) refers to drop off (or pickup) of air passenger by a companion in a private vehicle; companion drives vehicle away from (brings vehicle to) airport
(b) except for passengers staying at hotels served directly by airport bus. See also note (g).
(c) refers to trip by van or taxi to pick up passenger, or trip by passenger to transit or airport bus stop
(d) assuming ride given by someone at air traveler's home, workplace, or other origin; if driver located elsewhere, a pickup trip to air traveler's location becomes necessary
(e) assuming air passenger uses airport area transport (bus or rail shuttle)
(f) except for passengers destined to that part of airport in immediate vicinity of transit stop(s)
(g) typically closer to desired door than transit but not as close as other modes

Characteristics Favoring D/D Modes

Modal split analysis information for airport ground transport modes is sparse; consequently, a list of characteristics affecting demand for the various modes has been developed (Table 2). Characteristics are grouped into three sets relating to the individual passenger, to the ground trip, or to each mode; factors likely to favor the various D/D modes are shown in boldface. They include the following:

- Relatively short time available to travel to or from the airport (e.g., departing on an early morning flight, arriving on a flight with short lead time for an appointment, or arriving late at night),
- Arrival after a long flight,
- Limited mobility of one or more persons in the travel party (e.g., small children, the aged, or handicapped persons),
- Difficult baggage (heavy, bulky, or many pieces), and
- Adverse weather (heat, cold, or precipitation).

Many passengers to whom these characteristics apply will choose D/D vans, especially if one or more of the following conditions are present:

- Private automobile not available;
- Trip duration of many days, resulting in high airport parking costs;
- Travel costs or taxi use not reimbursed by others;
- No need for rental car during stay;
- Unfamiliarity with the geography of the region or with alternative public transportation options; and
- Familiarity with D/D van service through one or more of the following:
  - –Traveler's own past experience;
  - –Hotel, employer, or client established D/D van user; or
  - –Information on D/D van service readily available.

TABLE 2 Characteristics Affecting Choice of Airport Ground Transport Mode

CHARACTERISTIC	ALTERNATIVES (**bold** alternatives likely to favor one of the D/D modes)
PASSENGER-RELATED	
Passenger home location	resident visitor
Time available for trip to/from airport	**short** ample
Trip purpose	work-related (includes school) personal business social/recreational
Size of Ground Transport party	1 **>1**
Walking ability	not limited **limited (small child; aged; handicapped)**
Baggage	handled conveniently by air traveler **not handled conveniently by air traveler** (heavy and/or bulky and/or many pieces)
TRIP-RELATED	
Ground trip direction	to airport **from airport : after long trip, e.g. > 6 hrs (a)** after trip < 6 hrs (a)
Ground trip end	non-hotel locations **hotels/motels : served directly by airport bus (b)** **airport area (c)** other
Flight Arrival or Departure Time	**early, e.g.< 07 (a)** midday **late, e.g. > 21 (a)**
Weather	favorable (moderate, dry) **adverse (heat, cold, precipitation)**
MODE-RELATED	
Time between airport and O or D	(depend on specific location)
Cost (Fare; vehicle operating cost; parking; etc.)	(depend on airport, carrier, trip duration, etc.)
User Information (For-hire Carriers only - start time, duration, fare, etc.)	**readily accessible** difficult to obtain
Comfort (waiting, riding)	comfortable uncomfortable

(a) Approximate indication of 'long', 'early', 'late'
(b) Airport Bus serves as D/D mode
(c) Hotel Shuttle serves as D/D mode

Classification developed by the authors.

Concentrations of Demand

The wide dispersal in space and time of the regional origins and destinations of air travelers poses problems for the D/D van operator. For D/D vans to offer the economy of shared rides, there must be rides to share. Individual residences and businesses are likely to generate only one air-party trip at a time. A greater concentration of demand can be found at large hotels.

Typically, a few leading hotels will be served directly by scheduled airport buses. For competitive reasons, other hotels and motels often wish to provide a direct connection for trips to and from the airport. Hotels near the airport generally provide their own shuttle services. Many of the hotels farther away will use a selected D/D van operator regularly. This arrangement offers advantages to both the hotel guest and carrier: the hotel guest has convenient access to D/D van service information, and the carrier has a greater likelihood of picking up several passengers at one stop and of short distances between stops in the hotel district.

An equally important aspect of demand concentration is the problem of providing service to areas with low rates of air trip generation. In typical suburban or rural areas, it may be necessary to combine trips from locations many miles apart. Doing so increases the circuity involved in driving between pick-up or drop-off locations, which in turn increases the travel time for all users except the last to be picked up or the first to be dropped off. This problem is exacerbated if the market is divided among several carriers.

INTERMODAL COMPARISONS OF FARES AND SERVICE

The market for airport ground transport is highly competitive. Each mode offers a different mix of fare and service characteristics that needs to be considered in comparing modes.

Fares

D/D van operators typically charge fares that are intermediate between airport bus and taxi, with the fares being much closer to those of the bus. Taxi fares, however, are *per party* whereas airport bus and D/D van fares are *per person*; for multiperson parties, many D/D van carriers charge a reduced fare for the additional persons.

Fares generally vary with distance, but the relationship is not consistent in all cases. Other factors may enter: load factor (one-way and roundtrip), bridge tolls, fares charged by competitors, and market density.

Comparative Performance

The various ground transport modes differ in many performance characteristics: access to line haul, vehicle capacity, routing, and others. Comparisons based on actual performance are difficult. To examine how D/D van service compares with other modes, a hypothetical comparison between six major modes was designed that would make the modes commensurate. The comparison is based on the scenario that follows.

Twelve air passengers, clustered in the same community within a metropolitan area, are traveling to the airport at approximately the same time. They are considered to be traveling first as 12 separate individuals, then as parties of 2, 3, and 4 persons. Trips consist mainly of two segments—access and line haul. Parameters for the trips are specified in Table 3.

The performance of each mode is estimated in three measures:

- Vehicle kilometers (vehicle miles) traveled (VKT): indicator of contribution to congestion, air pollution, and energy consumption;
- Person minutes required: total time used by the air passengers as well as those transporting them; and
- User costs incurred: fares paid to common carriers and cost of operating private vehicles.

Each of these measures represents a form of input or cost to be constrained or minimized for optimal operation. VKT is only an indirect measure of emissions, energy consumption, and contribution to congestion but is useful as a broad indicator of relative performance; it should be recognized that impacts per vehicle-kilometer not only vary from mode to mode but also can vary with specific situations, such as availability of high-occupancy vehicle (HOV) lanes. Detailed analysis is likely to be necessary to understand the trade-offs in a given situation.

Assumptions

The following is assumed:

- *Public transit.* Each party is brought separately by private vehicle to the trunk line transit stop, an average distance of 3 km (1.9 mi); passenger and driver wait 10 min for an express bus. Air passengers then travel approximately 40 km (25 mi) to the airport (the line haul segment), mainly by freeway, transferring once en route to another express bus. The private vehicle driver returns to the point of origin. Bus driver time is included in total person minutes required, based on an average load of 12 persons per bus.
- *Airport bus.* The access trip to the airport bus stop is longer and includes some freeway travel. The line haul trip therefore is somewhat shorter; it has fewer stops and no transfer. Bus driver time is included, based on an average load of 12 persons per bus.
- *D/D van service.* Vans are limited to four stops and eight passengers; three vans are needed for the single passengers, two for multiperson parties. The second and additional members of the party get a 25 percent fare reduction. The van travels a 6-km (3.7-mi) deadhead to pick up the first passenger. After completing the pickups, the van travels another access distance of 2 km (1.2 mi) on local streets and then nonstop on the freeway to the airport. The times of the van drivers are included.

Information for the other three modes was developed similarly: taxis, private cars dropping air passengers off at the airport ("car passengers"), and private cars parked at the airport by the air passengers ("self-drivers"). Taxi VKT includes a 6-km (3.7-mi) deadhead to pick up the passenger. Times of taxi drivers and companions are included, as is the self-driver's time to park. Self-driver parking cost is based on an average trip lasting 2.5 days and is divided equally between trips to and from the airport.

Results

Performance measures for the 12 air passengers traveling individually are given in Table 4 for various trip elements:

TABLE 3 Specifications for Hypothetical Comparison

Variable and Trip Element	Unit	Airport Ground Transportation Mode: Transit	Airport Bus	D/D Van	Taxi	Car Psgr	Self Driver
Distance							
Pickup Trip	km			6	6		
Access to Line Haul	km	3	5	2	3	3	3
Line Haul	km	40	38	40	40	40	40
Terminal to Parking	km						2
Between Pickup Stops	km			1.5			
Speed							
Pickup Trip	km/hr			25	25		
Access to Line Haul	km/hr	25	30	25	25	25	25
Line Haul	km/hr	65	70	80	80	80	80
Terminal to Parking	km/hr						25
Time							
Transfer Time							
Access to mode	min/trfr	10	10				5 (a)
En Route	min/trfr	10					
Stop Time - pickup (b)	min/stop			3; 3.3; 3.7; 4			
Trip Duration - Average	days						2.5
Cost							
Private Vehicle	$/km	0.15	0.15			0.15	0.15
Fare	$/psgr	4	10	20			
	$/party				50		
Parking	$/car/day						9

(a) car to parking shuttle
(b) varies with party size

TABLE 4 Hypothetical Comparison: Performance Measures for 12 Parties of One Person Each

Unit	Trip Element	Airport Ground Transport Mode: Transit	Airport Bus	D/D Van	Taxi	Car Psgr	Self Driver
Vehicle kilometers	Pickup trip	0	0	32	72	0	0
	Access to line haul	72	120	6	36	72	36
	Line haul	40	38	120	480	960	480
	Parking	0	0	0	0	0	28
	Total	112	158	158	588	1032	544
	Per air passenger	9.3	13.2	13.1	49.0	86.0	45.3
Person minutes	Pickup trip	0	0	230	173	0	0
	Access to line haul	259	360	72	173	259	86
	Transfer	360	240	0	0	0	60
	Line haul	480	423	450	720	1080	360
	Parking	0	0	0	0	0	115
	Total	1099	1023	752	1066	1339	622
	Per air passenger	92	85	63	89	112	52
User cost ($)	Pickup trip	0	0	0	0	0	0
	Access to line haul	11	18	0	0	11	5
	Line haul	48	120	240	600	144	72
	Parking	0	0	0	0	0	135
	Total	59	138	240	600	155	212
	Per air passenger	4.90	11.50	20.00	50.00	12.90	17.70

- Pickup trip by a D/D vehicle (van or taxi) to the passenger's point of origin,
- Access trip via local streets to the freeway,
- Line haul trip along the freeway route to the airport, and
- Transfers and parking as required.

Results are aggregated for all trip elements and displayed on a per-passenger basis in Table 4 and Figure 1. As can be seen from the table and the figure,

- The shared-ride modes (transit, airport bus, and D/D van) require far fewer VKT than the exclusive-ride modes of taxi, car passenger, and self-drive.
- Person minutes reflect labor intensity: self-drivers require the least time; D/D vans, the next least; those passengers dropped off at the airport by a driver who must make the entire roundtrip, the most. The other modes require fairly similar amounts of time.
- Taxi is by far the most expensive mode, and public transit is the least expensive; the other modes are grouped quite closely. Person minutes are broken down between air passenger time and time for the person driving the air passenger in Figure 2. Driver time varies from zero in the self-driver mode to twice the air passenger time in the car passenger mode.

The same categories of results were developed for party sizes of two, three, and four persons. They are summarized in Table 5 per passenger and per party; results for parties of one and four are compared in Figures 3 through 5. The table and figures indicate the sensitivity of each mode to economy of scale. In general, transit and airport bus reflect some savings in vehicle kilometers and person minutes per passenger with increasing party size, primarily due to economy of scale in the access segment. The automobile-based modes of taxi, car passenger, and self-driver show much greater decreases in VKT and user cost per passenger; taxi and car passenger also decrease in person minutes because fewer drivers are required.

User cost variation indicates the nature of the cost to the passenger: if cost is variable, that is, based on individual fares as in the shared-ride modes, there is little economy of scale as party size increases. If cost is fixed, as in the modes using automobiles, distribution over larger party sizes results in sharp decreases in cost per passenger.

D/D vans occupy an intermediate position in the performance measures, reflecting their role as a consolidator able to achieve some economy of scale even with a few passengers. Person minutes are low for all party sizes because less driver labor is required in the access segment than for transit and airport bus, and less labor is required in the line haul segment than for taxis and car passengers; parking is not necessary. VKT are low for single passengers and do not decrease greatly with party size. User costs are significantly lower than taxi for single-person parties, but, under the assumptions of this comparison, D/D vans gradually lose that advantage as party size increases.

A survey of air travel parties at San Francisco International Airport (*3*) indicated an average party size of about 1.5; whereas more than half of all air travel parties consisted of only one person, more than half of all air passengers were in multiperson parties (mostly of two to four persons). Ground transport parties are not necessarily identical in size to air travel parties: they may include greeters and well-wishers; different members of the same air party may travel in different vehicles; and a single vehicle may carry several air parties. The survey addressed the number of greeters and well-wishers but not the other aspects of ground transport party size.

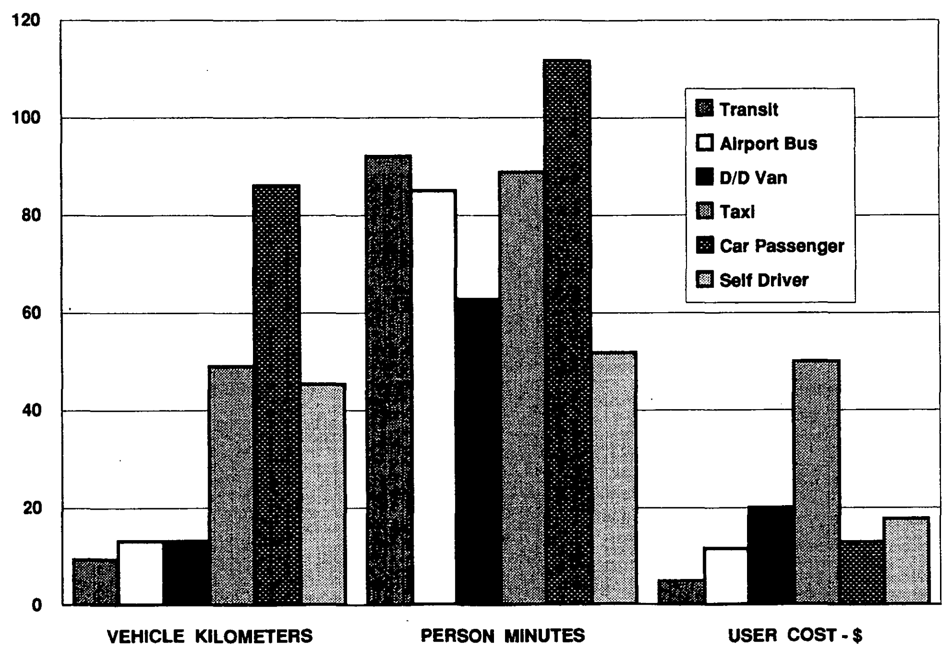

FIGURE 1 Performance characteristics per passenger, one-person parties traveling to airport.

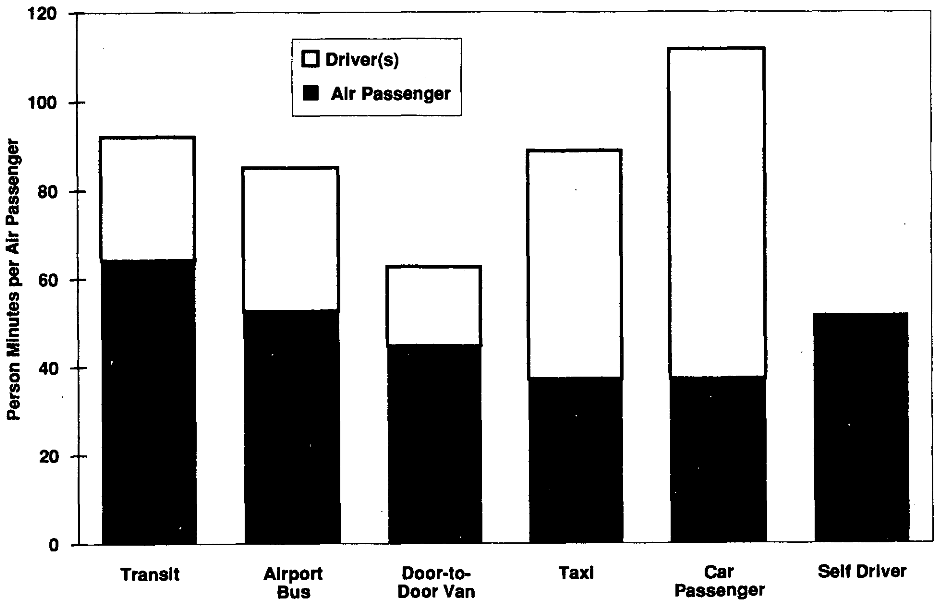

FIGURE 2 Person minutes required, single air passengers and drivers.

The intermodal comparison is sensitive to several parameters in addition to party size; among them are

- Air trip duration, which affects the parking cost of self-driver parties at the airport;
- Access mode to airport bus (or transit): sharp cost increases if taxi were used instead of private car;
- Access distance to airport bus and transit stops; and
- For D/D vans, average distance between pickup stops and the relationship between pickup distance and total distance to the airport.

Many issues arise in the design of this kind of comparison; among them are

- *Allocation of common costs.* Such common cost allocation includes the following:
  –Transit and airport bus driver time are shared by passengers outside the sample group, and
  –D/D van and taxi have waits of varying lengths between revenue trips.
- *Accounting for the cost of driver time.* If the air passenger is driven to the airport by a common carrier (transit, airporter, van, or

TABLE 5 Performance Measures for Ground Transport Parties of Various Sizes

	Airport Ground Transport Mode							
	Unit	Party Size	Transit	Airport Bus	D/D Van	Taxi	Car Psgr	Self Driver
Per air passenger	Vehicle kilometers	1	9.3	13.2	13.1	49.0	86.0	45.3
		2	6.3	8.2	8.5	24.5	43.0	22.8
		3	5.3	6.5	8.5	16.3	28.7	15.3
		4	4.8	5.7	8.4	12.3	21.5	11.6
	Person minutes	1	92	85	63	89	112	52
		2	79	70	53	63	74	52
		3	75	65	48	54	62	52
		4	73	63	47	50	56	52
	User cost ($)	1	4.90	11.50	20.00	50.00	12.90	17.70
		2	4.45	10.75	17.50	25.00	6.45	8.85
		3	4.30	10.50	16.67	16.67	4.30	5.90
		4	4.23	10.38	16.25	12.50	3.23	4.43
Per party	Vehicle kilometers	1	9.3	13.2	13.1	49.0	86.0	45.3
		2	12.7	16.3	17.0	49.0	86.0	45.7
		3	16.0	19.5	25.5	49.0	86.0	46.0
		4	19.3	22.7	33.5	49.0	86.0	46.3
	Person minutes	1	92	85	63	89	112	52
		2	158	140	106	126	149	104
		3	225	195	145	163	186	155
		4	292	252	187	200	223	207
	User cost ($)	1	4.90	11.50	20.00	50.00	12.90	17.70
		2	8.90	21.50	35.00	50.00	12.90	17.70
		3	12.90	31.50	50.00	50.00	12.90	17.70
		4	16.90	41.50	65.00	50.00	12.90	17.70

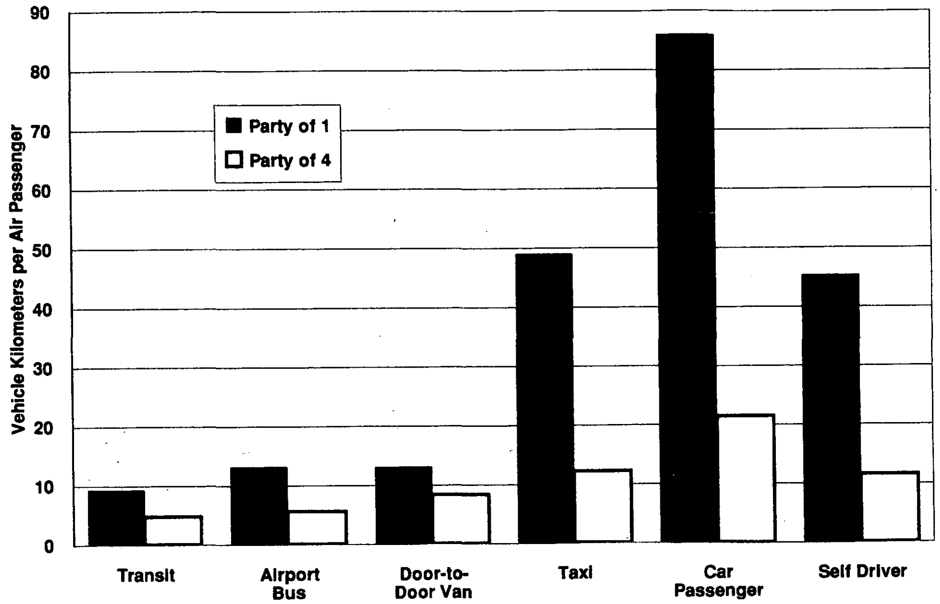

FIGURE 3 Vehicle distances for parties of one and four.

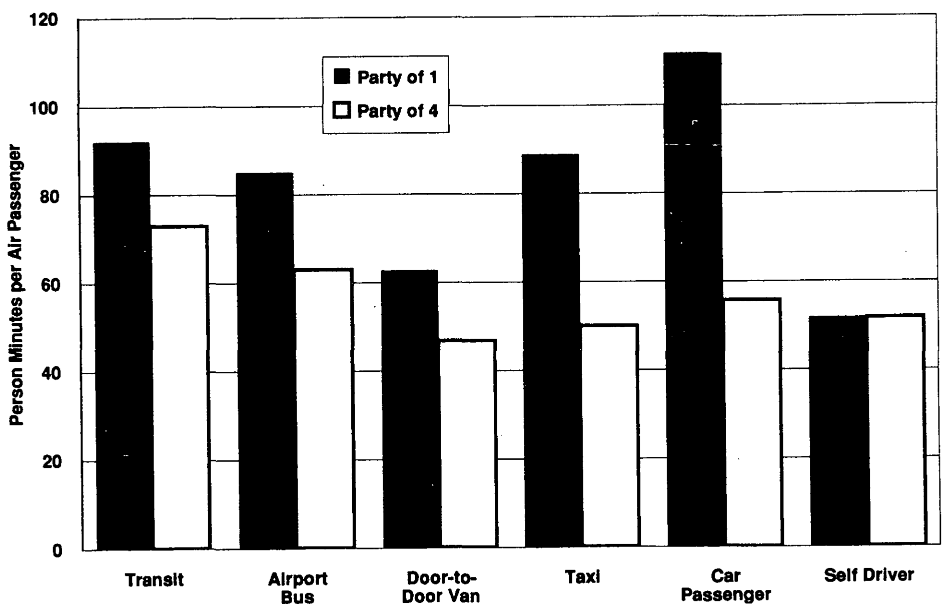

FIGURE 4 Person minutes for parties of one.

taxi), the cost of the driver's time is reflected in the fare, although public transit fares typically cover only a fraction of operating costs. In the car passenger mode, the driver time is included in person minutes, but no cost is included in user costs.

- *Accounting for the cost of air passenger time.* Should the ground transport time of air passengers be assigned a cost? If so, how should that cost relate to that of drivers?

Although there is some artificiality to the basic scenario and many of the values shown are greatly simplified, the comparison helps to understand the dynamics of the airport ground transport market. It should be recognized, however, that the results are sensitive to the assumptions made in the analysis; they should not be used as a basis for formulating policies without checking whether the assumptions match the situation in question.

MANAGEMENT ISSUES IN D/D VAN SERVICE

Various parties are involved in D/D van service operations; their objectives differ, as follows:

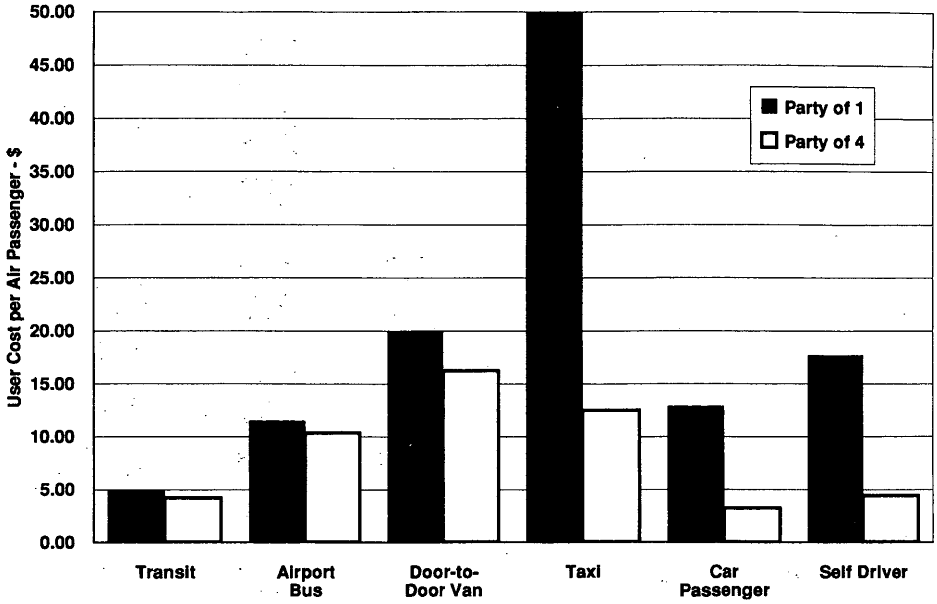

FIGURE 5 User costs for parties of one and four.

- Passenger—minimize wait time, travel time en route, intermediate stops, and circuity;
- Carrier—maximize passengers and net revenue per trip; and
- Airport—provide high-quality service to the airport user, avoid curbfront congestion, and minimize enforcement requirements.

In attempting to achieve its own objectives while considering those of the other parties, management of the D/D van operation faces a number of difficult trade-offs and optimization issues.

Service Standards

For the key attributes of D/D van service—demand responsive, flexible schedule, and flexible route—to benefit the passenger, some limits must be set so that the passenger completes the trip without excessive delay due to waiting time and detours caused by serving too many other passengers with trip ends that are dispersed too widely. Management needs to set service standards in order to compete successfully against other modes and other D/D van carriers. Standards may apply to such parameters as the following:

- Maximum passenger waiting time before departure from the airport,
- Maximum passenger en route time for a destination point or zone, and
- Minimum lead time before flight departure to arrive at the airport.

In an attempt to improve the quality of service offered to airport passengers, San Francisco International Airport has proposed a D/D van service agreement that specifies maximum passenger waiting times and headways (*4*). The challenge to management is to set a standard high enough to attract passengers, yet not so high that it dilutes load factor and leads to unprofitable operation.

Dispatching

Dispatching D/D vans is a difficult problem in either direction. Dispatching vans outbound *from* the airport may be constrained by service standards on maximum waiting time and headways, as well as by limitations on airport curb space and efforts to minimize airport roadway use in picking up passengers at the various terminal locations.

Dispatching the vans for trips *to* the airport is even more difficult. Pickup times for trips to the airport should deliver the passenger to the airport with sufficient time before flight departure (typically 1 hr, unless the passenger requests a different lead time). However, reservations are made at different times by passengers headed for different flights and do not come in any particular order. Yet a pickup time must be assigned to each party when the reservation is made, without knowing what reservations will be made later and where those pickups will occur. Service standards for maximum pickup time and minimum arrival time before flight departure establish a time window within which a pickup must take place. As reservations come in, they can be assigned pickup times within their window, based on their location in the service zone, to create reasonable sequence of pickup locations and times. The challenge is to combine the reservations and dispatching functions effectively. With multiple carriers the traveler wishes to know which carrier has a van that can take him or her to or from the airport with the least inconvenience. This, however, is a function of dispatching logic. Emerging information technologies, such as interactive cable or computer services, eventually may allow travelers to select the most appropriate carrier in real time, with significant gains in efficiency for both travelers and carriers.

User Information

The flexibility of D/D van service generates uncertainties for the potential passenger, particularly on trips outbound from the airport.

For example, when will the van arrive? when will it leave? when will the passenger reach his or her destination? These uncertainties are much smaller in the competing modes of public transit and airport bus. The challenge to D/D van managers is to provide readily accessible, clear, and accurate answers to these basic questions. Variable message signs and other technologies are available. An ultimate goal would be to provide landside user information of the same quality, completeness, and convenience as the flight information provided by the airlines to passengers at the airport.

CONCLUSIONS

During the past two decades, D/D van service has moved from early experimentation to the role of a major mode in airport ground transportation. It appears to have the potential for considerable additional growth. The long-term trend in transportation policy to emphasize HOVs is likely to favor D/D vans. The same trend will require airport managers to reexamine the allocation of scarce curb space among the various modes and the role of parking revenues, both now characterized by the traditional dominance of the private automobile in airport ground transport.

Airports cannot expect to achieve major gains in average vehicle occupancy *and* maintain existing revenue streams from parking and ground transportation concession fees. Whereas the full implications of this go well beyond the scope of this paper, it is imperative that airport policies toward the different modes be based on a careful analysis of their relative contribution toward policy concerns and objectives, including congestion, emissions, curb occupancy, and revenues, on a per-passenger (not per-vehicle) basis.

D/D van service is well suited to the needs of certain segments of the air traveling public; as long as reasonable passenger loads can be maintained, it compares well to other ground transport modes in requirements for vehicle kilometers (vehicle miles) and user time and cost.

Carrier management is faced with a number of complex issues in the effort to run an operation that provides both a high level of service to the public and a return to its owners. Carrier management as well as airport management would benefit from additions to the relatively small body of information on D/D van operations now available. The modal comparisons presented in this paper illustrate a potential framework for establishing policy toward the different modes. These comparisons can be extended to better reflect distributions of party size, trip duration, and other parameters according to the actual situation at a given airport. Likewise, the setting of service standards can be aided by data from actual experience. These and other steps can lead to the formulation of improved models of D/D van operations and of modal choice in airport ground transport.

Particularly needed are studies of the effect of trip end density on the performance of D/D van service. In low-density markets, circuity and waiting time involved in combining enough air parties to achieve successful load factors may significantly reduce the attractiveness of this mode. In such a situation, carriers must give careful consideration to charging higher fares in order to reduce the break-even load factor and hence the circuity and waiting time involved. Better models should help management of carriers and airports to take the steps needed for D/D van service to achieve its full potential.

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