7TH WCTR
SYDNEY AUSTRALIA
1995

TOPIC 8
AVIATION AND AIRPORTS

REDUCING AIRPORT TERMINAL CONGESTION THROUGH AUTOMATION

ATA M. KHAN
Department of Civil and Environmental Engineering
Carleton University, Ottawa CANADA K1S 5B6

ROLAND ROOVERS
D.S. Lea Associates (On Contract)
Consulting Engineers and Planners, Toronto CANADA

Abstract

Airports around the world are finding it difficult to accommodate rapidly growing peak period travel demand. Existing and new airports find it costly to provide space and maintain an acceptable level of service in many parts of the terminal building. There is a link between efficiency of service at airport terminals attainable through high technology applications and space standards, especially in queuing areas.

INTRODUCTION

For any area in the terminal building where queues occur (eg airline check-in counters, baggage collection, passport and immigration control), efficient use of valuable space is a necessity. Also, the space standards used in some parts of the terminal building are coming into question in terms of their cost-effectiveness. In recent years, some progress has been made in automation of selected airport functions. The baggage sorting process is an example of much innovation. However, there is further potential to apply computer-communications and display technologies with the objective of improving service to airport users and at the same time to increase the throughput of terminal processors. This paper examines three areas where queuing of terminal building users is a major problem. These are: airline check-in, passport control, and baggage claim. In these areas, service rates can be increased through various degrees of automation, resulting in improved levels of service to users and enhanced use of costly and scarce terminal space.

PROBLEM DESCRIPTION

Congestion at airports has been an issue of growing concern in North America and Europe. Numerous North American airports have been congested for some time (Transportation Research Board 1987). According to a study sponsored by the International Air Transport Association (IATA), without enhancement, 16 airports in Europe will be capacity constrained by the end of this decade. By the year 2000, losses to national economies due to constrained growth will amount to almost US $10 billion per year (SRI International/IATA 1990). IATA has organized an international campaign to publicize the enormous economic and social costs of failure to solve aviation's congestion problem. Without a cooperative solution between governments and the aviation industry, the Asia/Pacific region may experience airspace and airport congestion problems (IATA 1991).

As air travel demand increases, airlines and other agencies will have to process more passengers per unit of time (eg hourly, daily). In addition to higher demand for serving passengers with origins or destinations in the regions, the transfer of passengers between flights causes peaking of demand for service and facilities, particularly at major hub airports. Traditionally, airport authorities have accommodated rising demand for air travel by increasing supply of facilities. New airports were built, new terminal buildings were added and existing terminals were expanded. In recent years, due to environmental and social impacts, it has become difficult to expand capacity in order to accommodate growing demand for air travel. The airport authorities have resorted to operational measures in order to lessen constraints to flow of passengers. Signage was improved in order to make terminals user friendly. Additionally, some technology improvements have been made primarily in the baggage handling area. Despite all efforts made, there appears to be a chronic problem of growing congestion that needs to be addressed.

RESEARCH APPROACH

The research framework was devised to test space implications of improving service rates (Figure 1). The airport landside system was characterized in terms of processors and queue formation. Data acquisition activity followed next. Queuing models were defined and calibrated. Under the scenario of existing procedures and technology, processors were simulated and cost of space under existing procedures was estimated. A second scenario was defined which calls for applications of new technology. Processors were simulated and space as well as cost implications were determined. A comparison of two scenarios led to the estimation of saving, in cost of space.

The methodology uses queuing of airport users to create design functions that link observed arrival rate to the service rate and to the persons waiting in line at various processors. Then with such functions, the observed rate at a processor gives the average queue length. Knowing the queue length, the area and cost is found for a given level of service. With new technology, service rates are increased and a different queue length, area, and cost is found.

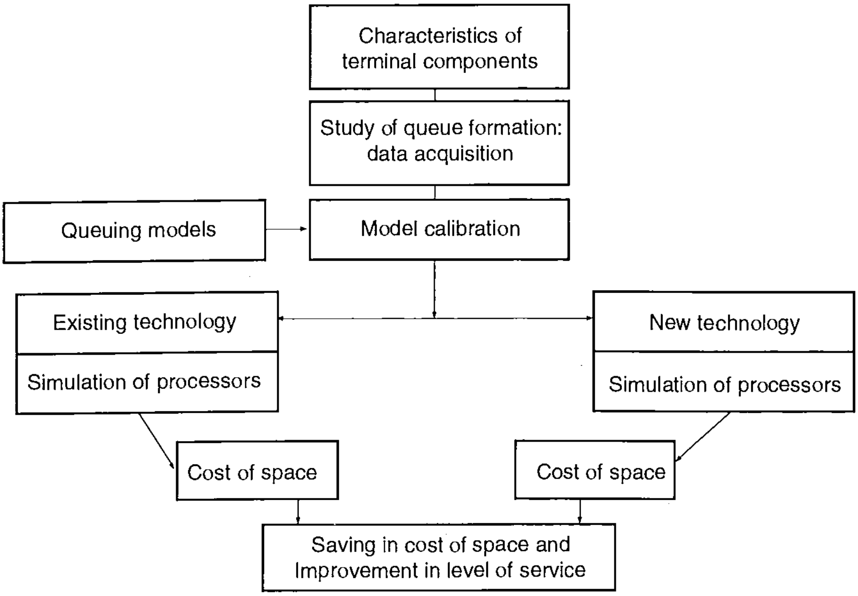

Figure 1 **Study methodology**

MODELLING CONGESTION

Airport terminal components

For a systematic study of an airport system, airport planners have found it useful to define its major functional components as: (a) regional access, (b) landside facilities and (c) airside facilities. The landside part consists of a number of interlinked subsystems, namely ground access, curb and parking, terminal building, gates and aircraft parking positions (Figure 2). The terminal building itself consists of a number of processors (eg airline check-in, security, baggage collection, etc.), holding areas (eg boarding lounge), and links (eg circulation areas) (Table 1).

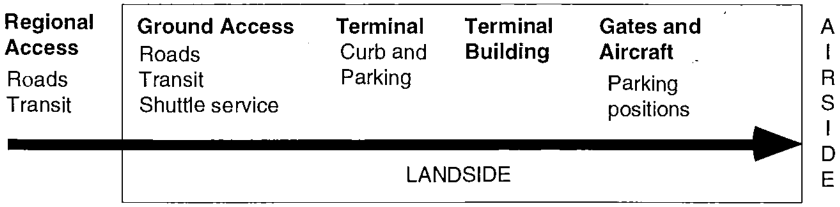

Figure 2 **Functional view of airport landside facilities**

Table 1 Enplaning and deplaning passenger subsystems

	Domestic & International	
	Enplaning	Deplaning
Reservoir	Ticketing queue area Check-in queue area Preclearance queue area Waiting (general) Security queue area Hold room, etc.	Primary inspection (PIL) queue area Baggage claim hall Secondary examination queue areas Waiting, etc.
Processor	Ticket counter Check-in Preclearance Secondary examinations	Primary inspection line Baggage claim devices Secondary examinations, etc.
Links	Corridors, Escalators, Elevators, Doorways, People Movers	

The individual subsystems of an airport are expected to interact in order to provide service to air passengers. Numerous paths of airport users through the components of the landside facilities are possible. Efficient interchanges between facilities are essential. The challenge for airport planners is to ensure that the various landside facilities offer users an acceptable level of service, do not become bottlenecks, and at the same time exhibit cost-effectiveness from the perspective of airport management and others responsible for supply of facilities.

In the process of designing landside facilities, a key initial step is to estimate "peak traffic", based on the forecasting of traffic for the design year, design day and design hour. It is a requirement of the design process that the landside facilities should be able to serve a peak-period traffic, representing the design year's busy period conditions. The expectation is that the various landside facilities would cope with a usage level higher than the design peak level for a number of hours/periods during the year.

The airport terminal must provide the necessary components or processors so that passengers can transfer between aircraft and ground transportation modes (car, taxi, bus/limousine, and rail). There are also other parts of the airport terminal that do not relate directly to the transfer process. These are restaurant/snack-bar, gift shop, smoke shop, post office, amusement centre, wash rooms, administrative offices, and non-public areas. In order to study service needs, queue formation and space implications, it is necessary to characterize the operating practices at each component of interest and is beneficial to study the linkages. It is recognized that at large airports, there may be numerous paths used by passengers. Passengers divide themselves between parallel paths. In theory, different passengers may use different routes through the landside, depending upon their demand characteristics.

Queuing, service time and delay

In simulation of the various components of the airport terminal, two approaches are possible. The first approach is a deterministic assignment of flows to the network of nodes (processors) and links. The second approach is based on queuing model framework.

Realistically, the magnitude of traffic to be served during peak periods and its arrival pattern at each landside processor are stochastic. Also, the service time offered by the processors could be stochastic, although simplifying assumptions are frequently made so as to analyze the service variable as deterministic.

A number of examples of queuing models such as US Federal Aviation Administration (FAA) Landside Model are available (McKelvey 1988). In this later approach, the airport terminal is represented by a series of passenger processors that are linked to form a network used by enplaning and deplaning passengers. The operations of processors are represented as queuing phenomena. Terminal users arrive at the process in a random form, generally wait for service, and move to another processor following service. The computation of average passenger delay and service time at each processor in the network can be obtained from queuing and service models. These time elements are added to travel time between processors in order to find out overall time through the network.

Modelling of landside system has been advanced in recent years by previous researchers. The complexity of this system and considerable variation in its operation have been recognized in the literature. The Federation Aviation Administration's (FAA's) Airport Landside Model offers analytical queuing model utilizing closed-form mathematical equations and network analysis concepts. Further work has resulted in improvement to the original model. Also, other work has extended the model to handle intra-airport transportation systems for transfer type of passengers between different terminal units. In its present form, the model is able to estimate average passenger delay experienced during enplaning and deplaning activities (McKelvey 1988).

A number of landside computer simulation models that are in use at present have modelled the flow of passengers and queue formation by using deterministic assignment as well as probability distributions (Reed 1995). A number of deficiencies in the state of knowledge have been pointed out in the literature. Firstly, it has been suggested that the link between service rate, technology/operational procedures for improving service rate, space use and cost of providing space have not been investigated (TRB 1987). Secondly, the link between capacity, delay and service quality requires further research (Lemer 1987, Gosling 1987). Thirdly, further developments are required in procedures for the analysis of a sequenced network of passenger processors. For example, methodology is required for taking into account the variation of demand on downstream processors that might be caused by delays at upstream processors in the sequence (Omer and Khan 1988, TRB 1987). This paper is intended to address the first deficiency noted above. Further research is underway at Carleton University and elsewhere that would overcome other deficiencies.

A variety of operating procedures are used for passenger processors within the terminal building. For example, airline check-in practices differ. Some airlines require a single queue but have a number of counters open at any time. Other airlines follow the practice of independent multiple queues. Therefore, both single channel and multiple channel queuing models apply. For each queue in front of a service counter (station), the rule of first-in first-out (FIFO) queuing mechanism applies. At a baggage collection device, queues form in front of the device but the FIFO concept does not necessarily apply in rigid form.

Queuing models assume that demand is random. In this research, the assumption of a Poisson arrival distribution was verified. Also service rate is assumed to be random and the applicable distribution (ie negative exponential) was found for each processor.

For queuing at the check-in and preliminary inspection line (PIL) area, the single station model is to be used, although some airlines and airports follow the practice of a single queue with multiple stations. The single station model is the most practical for the airport scene. For example, the formation of a single long queue with baggage is not practical. The single station queue is straight and short in comparison with the multi-station queue model.

As noted earlier, both arrivals and service times are random variables. Arrivals are discrete random variables, and service times are continuous random variables. It is often appropriate to describe units arriving at a terminal by the Poisson probability distribution:

$$P(n) = [(at)^n e^{-at}]/n!$$

Where P(n) = probability of n arrivals in period t

a = mean arrival rate.

It is advantageous to focus on the time intervals or headways between successive arrivals rather than on the number of arrivals occurring during a stated interval of time. For a poisson process, it can be shown that the probability density function of inter-arrival times is:

$$f(t) = ae^{-at}$$

This equation, known as the negative exponential distribution, is commonly expressed as a cumulative distribution function. It expresses the probability of a headway, h, being greater than or equal to t and is represented by the integral of f(t) ranging from t to infinity or its equivalent:

$$P(h>=t) = \text{Integral of } f(t) \text{ ranging from t to infinity} = e^{-at}$$

In many queuing situations, the distribution of service times is also best described by a negative exponential distribution:

$$P(s>=t) = e^{-mt}$$

where

P(s>=t) = the probability that a randomly chosen service time, s, will be equal to or greater than t,

m = mean service rate (ie the no. of services per unit of time)

In this paper, for an illustration of queuing in airport terminals, the following assumptions are made:

- single station model
- arrival rate, a, is known (poisson distribution)
- service rate, m, is known (negative exponential distribution)
- steady state condition: m>a

From the queuing theory model, measures of performance (mop) of the queue can be found. These are: probability of having exactly n units in the system, average length of queue, and average waiting time spent in the queue.

The probability of having exactly n units in the system:

$$P(n) = (a/m)^n[1-(a/m)]$$

The average length of queue (number of persons):

$$L_q = [a^2/\{m(m-a)\}]$$

Average waiting time spent in the queue:

$$T_q = [a/\{m(a-m)\}]$$

Queuing theory can be used as a basis for the development of design functions for terminal processors. An examination of such functions would suggest that for a particular arrival rate, the queue length is more sensitive than the queue time to changes in service rates.

Design functions

For design purposes, the length of the queue equation is converted to space required for a particular processor (check-in, passport, and baggage claim areas). The area of the queue (A_q) is directly related to the number of people in the queue (L_q) by:

$$A_q = L_q \times APP$$

where APP is area per person, based on the level of service to be provided and space standards.

Service levels are presently established in terms of standards that an airport authority attempts to meet either in the form of space standards or in terms of operation (ie time) standards. There has also been an attempt to set standards in terms of both time and space. However, until recently, the interaction of time and space standards has never been examined (Mumayiz and Ashford 1986).

Presently, there is no widely accepted method for defining a design level of service and associated facility/space standards. This is not to suggest that individual airport authorities and International

Air Transportation Association (IATA) do not have their own guidelines on what they consider to be acceptable service levels. Also, the IATA standards have been adopted by some airport authorities. However, the airport community has not come up with level of service criteria that are widely used in a manner similar to those in the highway engineering field (Transportation Research Board 1985).

A comprehensive level of service framework was defined by Transport Canada in 1979 which was subsequently proposed by IATA. It is based on different levels of space provision with respect to levels of service A to F (Table 2). This approach ignored the relationship between space and time factors and assumed that level of service could be defined by space standards alone in a linear fashion.

A recent research study supervised by the author developed a utility-theoretic methodology for quantifying level of service by taking into account the time and space standards. It is an attempt to advance the framework based on LOS A to LOS F (Khan 1988, Omer 1990).

Table 2 Level of service (LOS) framework

Level	Description
A	Excellent level of service; very low density; condition of free flow; no delays
B	High level of service; low density; very little traffic interference and delay
C	Good level of service; acceptable level of density and delay; related subsystems in balance
D	Adequate level of service but delays incurred; high density; condition acceptable for short periods of time
E	Unacceptable level of service; represents limiting capacity of the facility; very high density; subsystems not in balance
F	Subsystem breakdown; unacceptable congestion and delay

	Level of Service & Sq.m/person					
	A	B	C	D	E	F
Check-in	1.6	1.4	1.2	1.0	0.8	
Wait/circulate	2.7	2.3	1.9	1.5	1.0	
Holdroom	1.4	1.2	1.0	0.8	0.6	
Bag claim area (excluding area for device)	1.6	1.4	1.2	1.0	0.8	
PIL	1.4	1.2	1.0	0.8	0.6	

Source: Transport Canada Standards 1979

NEW TECHNOLOGIES

New technologies are being developed for the airline check-in, passport control, and baggage handling functions. Actual service rates are not available yet for a number of these technologies, since some of these technologies have not been tested widely on real-time arrival rates. Manufacturers can only give an indication of estimated service rates—which imply a throughput increase of 25% or higher. While high technology advances are being applied successfully in road and rail modes and in the airside facilities of the airport, the air terminal part of the airport has not so far fully benefited from such advances. By using new technology to increase the service rate, growing volumes of air travel can be served in critical parts of the airport. The object of these technological systems is to provide fast, accurate, and accountable service to the user at the airline check-in, passport control, and baggage claim check-out areas.

Check-in

For the check-in area, advanced computer-communication systems can be used in the near future to speed up service. The two main organizations in airline telecommunications are ARINC

(Aeronautical Radio Inc.) in the United States and SITA (Societe Internationale de Telecommunications Aeronautiques) on the international scene. SITA, a non-profit airline co-operative, is extending the scope from the operation of telecommunication services to services ranging from reservations and departure controls to common-use check-in terminals at airports (Woolley 1984). Another company has developed CUTE (Common-Use Terminal Equipment), a development of great significance to airports as well as airlines. It enables a standard terminal at a check-in desk or elsewhere to be used by more than one airline, to access computer systems over SITA or their own networks. By using CUTE, an efficient use of space is accomplished.

Machine-readable ticket (MRT) and baggage tag systems have been developed but in the past, lack of International Air Transport Association (IATA) standardization has meant interline operations were not feasible. There are two methods: optical reader with bar code, using the ticket number to refer back to the information stored in the reservation systems; or magnetic stripe, which can carry the information on the ticket itself (Woolley 1984).

Another concept for the check-in area is the Integrated Circuit Card (IC Card) or Smart Card. Although the IC Card resembles a standard plastic credit card, it contains a tiny computer that can provide many additional features to the user than the machine readable ticket (Bailey 1987). The IC card can be interactive with the user whereas the MTR cannot. Through the use of the IC Card, at the check-in, the ticket data would be instantly available together with the passenger's seat selection. The allocated seat, departure gate and any baggage tag reference numbers could also be stored for the passenger's convenience.

The Automated Ticket and Boarding Pass (ATB) is a new generation of ticket that is used in North America and gradually being introduced in Europe and Asia. The ATB serves as a flight coupon as well as a boarding pass in one document. A magnetic strip containing all relevant data enables automatic reading of the information. The advantages are that it speeds up passenger processing, facilitates passenger/baggage reconciliation and provides data enabling fast and accurate yield control and revenue accounting. At present, although not all the ATBs have magnetic stripes, this is expected to become the rule in 1995. Furthermore, the IATA is considering developing a blank format ATB for use by other parts of the travel business such as railways, shipping lines, hotels, etc. (IATA 1992).

Preliminary inspection line (PIL)

To increase service rates in the passport control process, the ICAO's recommendation for the development of a machine-readable passport or passenger card (MRP) has resulted in such a product. This card is expected to accelerate individual clearance through passport controls, either by using electronic equipment or by visual inspection (ICAO 1980). The card is expected to provide the same privacy as conventional passports and to ensure better resistance to tampering. According to specifications, the passport can be optically read.

Another development with much potential benefits in the international travel area is the automation of information exchange. This is especially useful for passenger processing by immigration authorities. One of the techniques being tested is Advance Passenger Information. That is, passport details and flight information are sent to customs and immigration at destination ahead of flight arrival which enables details to be checked against national data bases before the passengers actually arrive in the airport. Future enhancements under consideration may involve linking machine readable travel documents and biometric identification, for example using a hand scanner (IATA 1992).

Baggage collection

To increase service rates in the baggage claim, the baggage must be handled faster. The thermal activation system, produced by Science Application, is to be used in scanning baggage. The instrument bombards objects with neutrons and measures the secondary radiation that indicates the presence of explosives (Ott 1987). The E-scan unit (developed by Astro Physics Research

Corporation) adds a colour dimension to X-ray screening and explosive detection. The object to be screened is subjected to two X-ray energy levels, which distinguish between organic and inorganic materials.

Statistics have shown that about one percent of airline baggage is misrouted. In order to address this problem, baggage tracking systems have been developed (Woolley 1984). One such system, BAGTRAC, is now being complemented by BAHAMAS (Baggage Handling and Management System). The BAHAMAS stores information on misrouting and generates automatically messages to tracing systems such as EASYTRAC and BAGTRAC (Woolley 1984).

The International Air Transportation Association (IATA) has been serving as the focal point for establishing industry standards for the acceptance, handling, transfer, security and tracing of baggage. The Joint Automated Baggage Working Group between IATA, the Air Transport Association of America and the Airports Association Council International is seeking an innovative way of tagging bags, based on a "licence plate". It carries a ten digit number indexed to a data base containing information on the passenger and destination. It can be machine-read as it moves on the high speed sorting system. A further development would be the use of radio frequency tagging (IATA 1992).

A number of new airports are applying automation in baggage handling. For example, the New Munich Airport is equipped with a fully automated baggage handling system that delivers bags from check-in positions to gates, gate to claim area and among gates. The system uses 1800 motors and can move 14000 pieces of luggage an hour (Futterman 1984).

EFFECT OF AUTOMATION ON PROCESSOR THROUGHPUT AND SPACE REQUIREMENTS

Data acquisition and analysis

Field studies were carried out at the Ottawa International Airport and the Pearson International Airport (Terminal 1), Toronto, in order to quantify demand and supply characteristics of selected processors. Data were collected on the arrival rate and service rate of the check-in, the P.I.L., and the baggage claim check-out areas. The arrival rates were recorded as the number of people arriving at a given queue every thirty seconds. From the data collected, the average arrival rates were calculated for the corresponding processes.

In addition to waiting time in the queue, the service rates were recorded as the number of minutes each person took at the various processors. The time was recorded when a person advanced to the processor and again when that person left. The difference between these times was taken as the service time (inverse of service rate).

The following observations can be made from the analyses:

- The observed arrival rates are Poisson distributions.
- The observed service times are negative exponential distributions (up to the time when service is exceptionally quick.
- As the service rate approaches the arrival rate, but still greater than the arrival rate, the queue length and corresponding space required and cost are unrealistically high. This is where the steady state condition fits in—the service rate must remain greater than the arrival rate.

The probability of arrival P(a) and the relative frequency of service times are presented in Table 3.

Table 3 Probability of arrivals (a) and relative frequency of service times (s)

Processor	Probability of Arrival Rate "a" P(a)	Relative Frequency of Service Times s
Check-in		
Ottawa	$e^{-0.279}[(0.279)^a/a!]$	$0.33e^{-0.33s}$
Toronto	$e^{-0.389}[(0.3898)^a/a!]$	$0.46e^{-0.46s}$
PIL		
Ottawa	$e^{-0.801}[(0.801)^a/a!]$	$0.955e^{-0.955s}$
Toronto	$e^{-0.810}[(0.810)^a/a!]$	$1.03e^{-1.03s}$
Baggage Claim		
Ottawa	$e^{-0.129}[(0.129)^a/a!]$	$0.156e^{-0.156s}$
Toronto	$e^{-0.121}[(0.121)^a/a!]$	$0.143e^{-0.143s}$

Space requirements

The length of queue was computed and was converted to space required for a particular processor (eg check-in, passport control, and baggage claim areas). The area per person (APP) factor is based on the nature of the processor (eg check-in) and the level of service. Table 2 shows Transport Canada's space standards for airport terminals. A description of the level of service is also provided in Table 2.

The level of service is defined as a measure of user-perceived operating conditions (eg the degree of congestion) at various processors, reservoirs, and links. The capacity of a subsystem (facility) is the maximum saturation level throughput (ie density or volume, depending upon the nature of the subsystem) that can be served under the prevailing subsystem (Omer and Khan 1988). For the estimation of queue areas, the level of service (LOS) C is suggested. At this level, there is stable flow of passengers and acceptable throughput.

Omer and Khan (1988) found that the most cost-effective LOS for design of airport landside facilities is LOS C. Furthermore LOS D could be used as the trigger point for capacity additions. Operations at LOS E on a sustained basis are uneconomical from the perspective of high "social cost". See Figure 3 for a conceptual illustration of this concept. An actual example was reported by Omer and Khan (1988).

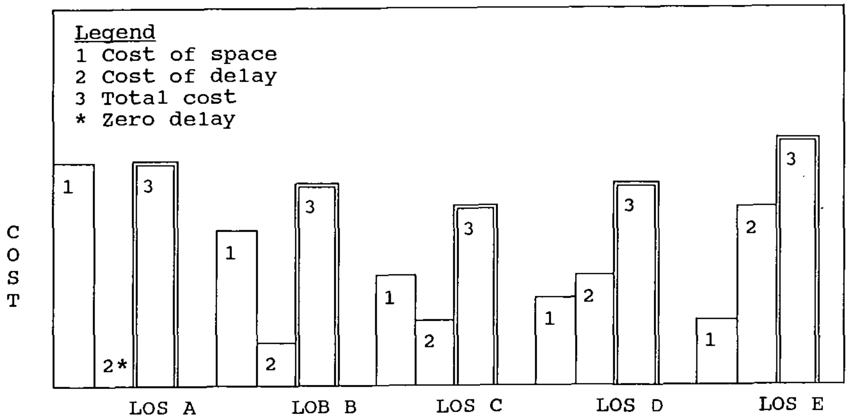

Figure 3 Facility size, cost and level of service

Using the known arrival and service rates for a processor at an airport, the effect of increasing the service rate was found. Therefore, for design purposes, if new technology such as machine-readable tickets can increase service rates by 25%, then the queue areas would decrease in size. These results are summarized in Table 4. Figures 4 and 5 show selected illustrations of the reduction of queue space owing to increased service rates.

The estimated terminal cost and throughput are important information items in the design stages because ultimately the design alternatives are judged on a cost-effectiveness basis. Since the queuing areas are part of the whole airport terminal, it is useful to get a feel for the cost of these components.

On the basis of estimates of reduced queue areas made possible by increased service rates and $/sq.m information, savings in space cost can be found. The percent reductions in space cost are of course identical to those of space savings due to a constant cost/sq.m.

Table 4 Reduction in queue area

Processor	Arrival rate (pers/ hour)	Existing Service Rate (pers/h)	Area/ Queue (sq.m)	Increased Service Rate (pers/h)	Area/ Queue (sq.m)	Reduction in Queue Area (%)
Check-in (per counter)						
Ottawa	16.73	19.80	5.52	24.75	1.69	69.4
Toronto	23.33	27.60	5.56	34.5	1.70	69.4
P.I.L. (per counter)						
Ottawa	48.06	57.30	4.36	71.63	1.37	68.6
Toronto	48.60	61.80	2.90	77.40	1.07	63.1
Baggage Claim (per queue)+						
Ottawa	7.74	9.36	4.74	11.70	1.55	67.3
Toronto	7.26	8.58	5.59	10.74	1.70	69.6

+ per queue in front of baggage claim device

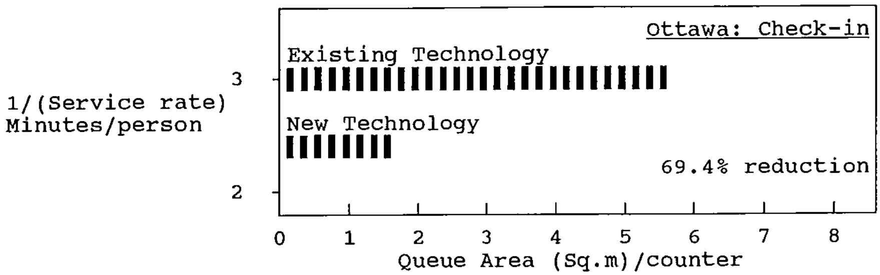

Figure 4 Reduction in queue area due to increased service rate: Check-in Ottawa (avg. arrival rate = 16.73 persons/hour or 1 person/3.59 min)

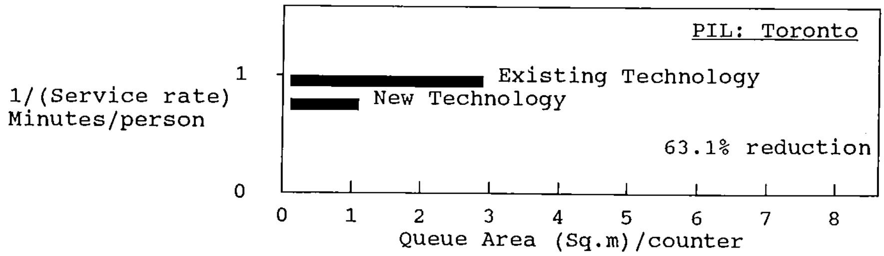

Figure 5 Reduction in queue area due to increased service rate: PIL Pearson Int'l Airport, Toronto (avg. arrival rate = 48.6 persons/hour or 1 person/1.23 min)

CONCLUSIONS

The use of technological and associated operational means are highly effective in reducing queuing time, queue areas and space costs. Even a modest 25% increase in the average service rate results in over 60% reduction of queue areas and their costs for check-in, PIL and baggage collection processors.

If the service rate is slightly greater than the arrival rate, then a 25% increase in the service rate is much appreciated in reducing the queue length, area, and cost. Conversely, if the service rate is much greater than the arrival rate then a 25% increase in the service is insignificant in reducing the queue length, area, and cost.

Airport planners and airlines cannot avoid addressing passenger terminal congestion problems by simply adding more space. A more cost-effective approach requires:

- monitoring the efficiency of processors at major airports, and
- adopting new technology for improving service rates and thus reducing space requirements.

ACKNOWLEDGMENT

This paper is based on research funded by the Natural Sciences and Engineering Research Council of Canada (NSERC).

REFERENCES

Airport Associations Coordinating Council (AACC) and International Air Transport Association (IATA) (1990) *Guidelines for Airport Capacity/Demand Management*, Second Edition, Geneva, Switzerland.

Bailey, G. (1987) Towards the Ticketless Society, *IATA Review*, 3/87.

Futterman, E.C. (1994) *The New Munich Airport*, Paper Presented at the Annual Meeting, Transportation Research Board, Washington, D.C.

Gosling, G.D. (1988) Introduction to Airport Landside Planning Techniques, *Transportation Research Record 1199*, Transportation Research Board, Washington, D.C., pp.1-3.

International Air Transport Association (IATA) (1992) Airports: Streamline Travel, *IATA Review*, 3/92, June/July, pp. 19-20.

IATA (1991) Congestion: Europe today, Asia Pacific Tomorrow, Congestion Update, *IATA Review*, 1/91.

IATA (1989) *Airport Terminals Reference Manual*, 7th Edition, Montreal.

IATA (1989) Automated Ticket/Boarding Pass (ATB), *Passenger Services Conference Resolutions Manual*, 9th Edition, Montreal.

IATA (1987) Industry Automation, *IATA Annual Report*, Montreal.

International Civil Aviation Organization (ICAO) (1983) ICAO Unveils Computer-Age Passport. *ICAO Bulletin*, Montreal, May, pp.34-35.

ICAO (1980) *A Passport with Machine Readable Capability*, Montreal.

Khan, A.M. (1986) Criteria for the evaluation of airport airside and landside level of service. Proceedings, *International Conference on Transportation Systems Studies*, December 18-22, 1986, Delhi, pp.27-34.

Lemer, A.C. (1988) Measuring Airport Landside Capacity, *Transportation Research Record 1199*, Transportation Research Board, Washington, D.C., pp. 12-18.

McKelvey, F.X. (1988) Use of an Analytical Queuing Model for Airport Terminal Design. *Transportation Research Record 1199*, Transportation Research Board, Washington, D.C., pp. 4-11.

Mumayiz, S. and Ashford, N. (1986) Methodology for Planning and Operations Management of Airport Terminal Facilities, *Transportation Research Record 1094*, Transportation Research Board.

Omer, K.F. (1990) *Passenger Terminal Level of Service Measurement: A Utility Theoretic Approach*, M.Eng. Thesis, Carleton University, Ottawa, Canada.

Omer, K.F. and Khan, A.M. (1988) Airport Landside Level of Service Estimation: A Utility Theoretic Approach, *Transportation Research Record 1199*, Transportation Research Board, pp. 33-40.

Ott, J. (1987) *New Technology Bomb Detectors Will Improve Airport Security*, AW&ST, Aug. 3.

Reed, K.A. (1995) Landside Computer Simulations Using the Airport landside Planning System (ALPS), JKH Mobility Services, Inc., Houston, Texas, *Transportation Research Board Paper No. 950785*, Presented at the 1995 Annual Meeting, Washington, D.C.

SRI International (1990) A European Planning Strategy for Air Traffic to the Year 2010, Europe Congestion - the Way Out, *IATA Review*, 1/90, Montreal.

Transport Canada (1979) *A Discussion paper on Level of Service Definition and Methodology for Calculating Airport Capacity*, Airport Services Branch, Ottawa, Canada.

Transportation Research Board (1987) *Measuring Airport Landside Capacity, Special Report 215*, National Research Council, Washington D.C.

Transportation Research Board (1985) *Highway Capacity Manual, Special Report 209*, Washington, D.C.

Woolley, D. (1984) Airline automation cuts costs, *Interavia*, 7/1984.