Airport Landside Level of Service Estimation: Utility Theoretic Approach

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The need for research on level of service criteria and standards for the design and evaluation of existing or proposed new landside facilities arises from the requirement that they reflect technical developments, enhanced knowledge of user preference and behavior, the need to increase the efficiency and cost-effectiveness of the airport system, and the uncertainties of air travel demand. In air transportation, by and large, reliance has been placed on arbitrary standards with hidden assumptions. This paper reports recent research on the interrelationship between space/service standards, user perceived value or utility of level of service, and cost. A framework is described for the study of level of service, based on the principles of utility and cost-effectiveness theories. Criteria for design and evaluation of landside facilities are discussed, and recommendations for further research are made.

Airport landside level of service and capacity have been topics of research interest over the past two decades or so (*1, 2*). More recently, owing to the critical nature of airport level of service issues, a number of studies have been initiated on the identification of the landside problem in general, and on capacity and service measures in particular. Some progress has been made in terms of defining service levels, based on degree of crowding and delays and so forth. A joint Federal Aviation Administration (FAA)/Transportation Research Board (TRB) study, published recently, serves as a background document on the various facets of the problem as well as international practices and standards (*3*). More research is needed, however, to define level of service gradations and capacity standards (*4, 5*).

A high priority placed on landside research is hardly surprising, given the critical need for innovative research on this topic. A number of agencies, which have established criteria and standards for the design of airport landside facilities, have come to realize that, by and large, reliance has been placed on design criteria that are limited in terms of accounting for the demand as well as the supply side concerns. It is now believed that design standards developed in the past were largely arbitrary, with hidden assumptions. Consequently, oversized facilities have been provided at a number of airports. Also, because of insufficient attention paid to strategic planning, inadequate understanding of user value structure, absence of studies on the cost-effectiveness of level of service, and lack of flexibility to adapt to changing traffic conditions, imbalances of demand and capacity have become apparent at some busy airports.

The objectives of the research reported here are twofold. First, it is intended that the importance of the interrelationship between the level of service and the cost (to users as well as suppliers) of facilities be highlighted, thus making a case for enhanced knowledge of measures for the design and assessment of airport landside facilities. Second, it is also intended that a framework be developed for estimating the utility (value in use) and cost-effectiveness of levels of service, based on the principles of utility (value) and cost-effectiveness theories.

In this research, application of utility and cost-effectiveness theories is illustrated for measuring user-perceived levels of service and for establishing economical design criteria. In contrast with previous approaches, airport terminal users are not asked to distinguish, directly, in the form of a single question, between various gradations of service quality consisting of multiattributes. Instead, through the use of the attitudinal survey technique, users are asked to indicate the relative importance of level of service factors (e.g., waiting time, processing time, space availability) and to rate each level of service attribute/factor through a semantic scaling method. In accordance with utility theory, the weighted rates are transformed to a relative value scale and then combined into a utility measure. From these utility values, level of service offered by a facility under prevailing conditions is inferred.

Through the investigation of a facility under various levels of usage and the correlation of user-perceived service quality (i.e., value in use or utility) with objectively measured performance indicators, space and service (e.g., time spent in a subsystem) thresholds can be defined. Also, through use of the principles of cost-effectiveness, the economics of providing various levels of service can be established. In this paper, following a discussion of the level of service issues and framework, the utility theoretic approach to level of service estimation and cost-effectiveness of level of service (and resulting facility size/designs) are covered.

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LEVEL OF SERVICE ISSUES

Historically, airport facilities have been planned and investment decisions made without much assistance from scientific research in refining design criteria and standards. The transportation profession is very familiar with the amount of research that went into the highway capacity area, which recently produced a third-generation capacity manual. Consequently, it is hardly surprising that in recent years, airports, more than any other type of transportation facility, have been criticized—in some cases, as examples of wasted resources and, in others, as a focal point of user discontent with the level of service. Indeed, the imbalance between demand and capacity at key components of airport terminals is a common occurrence.

There is apparently a genuine lack of knowledge about user acceptance of conditions at airports, as well as about the cost implications of providing various levels of service. Furthermore, the airport planning profession has not yet standardized its gradations of levels of service in the manner that the highway planning profession has done since 1965. The absence of an appropriate definition of level of service ranges and guidelines for design and evaluation criteria and standards has hindered efficiency in airport planning and operations (*6*).

Recent reviews of airport planning and investments in Canada have concluded that, in general, the level of service and unit cost of providing that service at airport systems are excessive. It was stated that a significant reduction in level of service could be achieved with minimum impacts on the air traveling public and the air carrier industry (*7*). Experience gained from Pearson (Toronto) and Dorval (Montreal) airports was quoted as evidence to suggest that some additional crowding does not lead airlines and passengers to curtail their use of airports (*8*).

While the aforementioned reviews give the impression of past oversupply of airport facilities, there are also cases where a number of interest groups are concerned about insufficient capacity to serve the growing demand. Considering that undesirable consequences exist for oversupply as well as for undersupply, the search for a balance between demand and supply over time should be an important objective of airport planning. An improved knowledge of appropriate design criteria and standards and the means to deal with the uncertain nature of future demand for services are of paramount importance. Table 1 describes some of the possible impacts of oversupply and undersupply of airport facilities.

Clearly, given the increasingly complex nature of airport planning, design, and investment decision making, the nonscientific treatment of capacity and level of service subjects is hardly acceptable. In fact, as is evident from the previously noted reviews, an improved knowledge of the interrelationships of level of service, capacity, and cost (to facility users as well as suppliers) is essential. A number of associated requirements are to be met as well. These include refining the measures for assessing the performance of airport landside subsystems and dealing with the uncertain nature of future air travel demand.

LEVEL OF SERVICE FRAMEWORK

Requirements for Facility Design and Evaluation

The landside part of the airport system consists of a number of interlinked subsystems that are intended to serve as processors, holding areas, and links (Table 2). The design process, in broad terms, is expected to yield cost-effective size and configuration of facilities, to ensure efficient interchanges between facilities, and also to meet other criteria (e.g., safety and security) (*9*).

In the design process shown in Figure 1, a key initial step is to estimate "peak traffic," which requires the forecasting of traffic for the design year, the design day, and the design hour. The prediction of profiles of aircraft and person/goods traffic demand is a necessary prerequisite for design and analysis of facilities. Given that future demand, especially beyond a five-year period, cannot be forecast with any degree of certainty, a recognition of sources of uncertainty and methods of coping with the uncertain nature of demand are required.

An airport's landside facilities are designed to serve a peak-period traffic that is supposed to represent the design year's busy period conditions (*10*). It is expected that the various landside subsystems will have to cope with a usage level higher than the design peak level for a number of hours/periods during the year. There is little agreement among airport agencies, however, about the definition of, or the approach to, measuring the planning and design peak period. Methods that have been used, namely, the *x*th (e.g., 90th) percentile traffic and the *n*th (e.g., 30th) highest hour in the year, are known to be deficient in capturing the true nature of the peak traffic profile (*6, 11*).

Airport planners in Canada, who have used the 90th percentile traffic in the past, are attempting to shift to a more realistic measure—the highest representative peak hour in the composite hourly traffic profile representing the busiest season. The busiest season is considered the year's three consecutive months with the highest average daily passenger traffic volume. To compare the two approaches, this new criterion would yield 91st–93rd percentile traffic for Pearson International Airport (Toronto) and would equate to 85th–88th percentile traffic at smaller airports (*11*).

As for other agencies, the Federal Aviation Administration (FAA) of the United States has suggested flexible guidelines that define the design peak hour as 6.25 percent to 20.00 percent of the busy day's total operations. Scheduled airlines in the United States generally design their facilities for the peak hour of the average day of the peak month of the selected design year. The British Airports Authority (BAA) applies its design standards in association with 95th percentile traffic. The Western European Air-

TABLE 1 POSSIBLE IMPACTS OF LANDSIDE FACILITY OVERSUPPLY AND UNDERSUPPLY

Interest Group[a]	Negative Impacts of Oversupply	Negative Impacts of Undersupply
Users	Increased charges to pay for oversized facilities	Congestion, delays; reduced level of service (inconvenience, cost of time, discomfort)
Carriers	Increased charges (fees, leases)	Cost of delay; reduced level of service offered; diversion of customers to other airports (carriers) and modes
Government (as airport owner)	Reduced revenues; political backlash	Political backlash; social loss due to congestion costs
Airport authority	Reduced revenue; increased overhead	Operational problems; complaints from travellers and carriers; loss of potential customers
Airport concessionaires	Increased charges (leases, fees); reduced revenue	Reduced level of service offered to customers; loss of potential customers

[a] Other interest groups are also impacted (e.g., land developers, adjacent property owners, environmentalists).

TABLE 2 ENPLANING AND DEPLANING PASSENGER SUBSYSTEMS (*9*)

	Enplaning	Deplaning
Sector	Domestic Canada–U.S.A. International	Domestic Canada–U.S.A. International
Reservoir	Ticketing queue area Check-in queue area Preclearance queue area Waiting (general) Security queue area Holdroom, etc.	Primary inspection (PIL) queue area Baggage claim hall Secondary examination queue areas Waiting, etc.
Processor	Ticket counter Check-in Preclearance Secondary examinations, etc.	Primary inspections line Baggage claim devices Secondary examinations, etc.
Links	Corridors Escalators Elevators Doorways People movers, etc.	

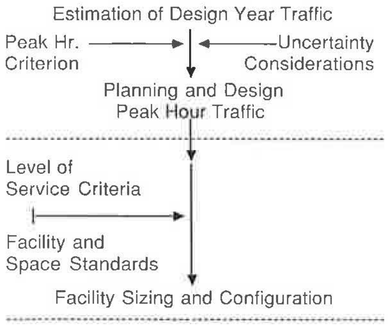


FIGURE 1 The design process.

ports Authority (WEAA) applies different criteria depending upon the site. A commonly used criterion, however, is the 30th busy hour (*9, 11, 12*).

Realistically, the proportional share of peak-hour traffic out of average-day, peak-month/season movement cannot be assumed with any degree of confidence to be a constant (e.g., 9 to 10 percent), particularly for large airports. As schedules are spread throughout the day at major airports, this percentage logically drops. Also, experience gained from airport studies suggests that the characteristics of peaking are largely airport-specific, depending upon the airport's location within the network. Recent experience indicates that the peaking phenomenon can be influenced through policies in pricing, marketing, incentives/disincentives, and especially (voluntary or imposed) scheduling.

For the development of supply strategies (i.e., type, size, and configuration of facilities and implementation schedule), level of service criteria and the associated space standards are required. Currently, widely recognized level of service criteria are not available. A more basic deficiency is the general absence of well-researched knowledge on this subject.

Airport planners in Canada have adopted the level of service framework used for planning and design of highway and pedestrian facilities for specifying operating conditions at airports. Table 3 presents a description of the various levels of service (LOS), ranging from LOS A (excellent) to LOS E (capacity) and LOS F (system breakdown).

In this research, level of service is defined as a measure that describes user-perceived operating conditions (e.g., the degree of congestion) at various processors, reservoirs, and links. The capacity of a subsystem (facility) is the maximum (saturation) level throughput (i.e., density or volume, depending on the nature of the subsystem) that can be served under prevailing conditions. Attempts have been made to study user-perceived level of service and behavioral aspects of landside operations (*13*). There are a number of reasons for adopting the LOS framework shown in Table 3 for the planning and design of landside facilities. As the experience of the highway transportation profession suggests, a framework based on the concepts of "ultimate" and "practical" capacities is difficult to operationalize and inflexible, because of the absence of a continuum of level of service falling from ideal conditions, to saturation, and ultimately to jam cases.

Another scheme, based on three levels of service, suffers from similar weaknesses without offering any advantages. It is recognized here that adopting LOS A to F does not simplify the essential task of identifying the most appropriate performance measures and ranges of performance that correspond to the various levels of service. From a planning and design perspective, the wider gradation of conditions represented by the LOS framework used for highway transportation has a logical appeal.

TABLE 3 LEVEL OF SERVICE (LOS) FRAMEWORK (*2, 6, 9*)

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

As for implementation of the LOS framework, a knowledge of the capacity of landside facilities as well as throughput at varying levels of service (i.e., densities, service flows) is required for planning and design activities. Also, information on acceptable levels of service as well as their cost-effectiveness is of growing interest. An important research finding is that the economic variable must be considered, given that a desired throughput level and the resulting quality of service are joint products with cost implications for airport authorities, airlines, and the traveling public. Economic considerations of landside planning and design have also been investigated in the past (*14*).

Design Criteria

In recent years, three types of criteria have become relevant for landside subsystem planning and design. These can be categorized as functional performance (i.e., operational effectiveness, safety and security, comfort, and convenience), flexibility (i.e., change/growth), and economy (i.e., cost and revenue/benefit balance) (*12*).

The operational effectiveness criterion is intended to ensure the smooth (without disruptions or other problems) functioning of the facility itself, as well as its interchanges with other facilities. The criterion's measures, which are diverse, relate to flow of traffic and delay. As for safety and security, the design of landside facilities is beginning to respond to these requirements. The passenger convenience/comfort criterion deals with a large number of factors, namely, travel time, walking distance, accessibility to amenities, service convenience, clarity of signage, and passengers' opportunity for communication about orientation and information (*12*).

Flexibility to accommodate growth and change is an important criterion, given the uncertainties of future traffic (in terms of numbers, user characteristics, and requirements) (*15, 16*). As noted earlier, there is a growing emphasis on economic factors in the provision of airport facilities. Therefore the criterion of economy is an important one, given pressures to reduce the level of service and economic constraints for capacity expansion or facility modernization. Operational measures include economic efficiency or cost-effectiveness as the basis for investment decisions. The airport research community has come to recognize that life-cycle costs (i.e., costs of construction, operation, maintenance, and rehabilitation) as well as airline and traveler costs are to be included in design (capacity, level of service) and investment decisions.

UTILITY THEORETIC APPROACH TO LEVEL OF SERVICE ESTIMATION

The state of knowledge is deficient in capacity and level of service characteristics of landside subsystems in their present form or as they can be affected by technical developments. According to current practice in airport planning and design, an ultimate capacity and a practical capacity are defined where an "acceptable" level of delay is used as a measure for practical capacity. The conceptual practical weaknesses in practical capacity approach have already been mentioned. In addition, the acceptability (to the user) of the amount of delay is subjectively established by planners, without definitive field studies.

The use of level of service framework (shown in Table 1), if appropriately supported with research on estimating the levels of service, would be an improvement on existing practice in the sense that a wider classification of user density or volume indices could be used to specify design standards and trigger points for capacity expansion. Table 4 provides a summary of performance measures for landside subsystems (*17, 18*). Criteria and standards for these facilities are not well developed. For apron/gates and the constituent parts of the terminal building, the practices and standards used by a number of organizations differ widely and are not supported by analyses.

In all cases reviewed, single values for space standards are quoted. Transport Canada's recently adopted space standards for selected landside subsystems, shown in Table 5, are a step in the right direction because they correspond to the various levels of service. The gradations are rather narrow, however, and were set subjectively.

The application of utility theory is advanced here for measuring the levels of service and establishing realistic density/capacity or volume/capacity ratios (i.e, indices) that correspond to the various LOS and space standards for landside facilities. The use of density (i.e., occupancy per unit area at any time) as a measure of the intensity of usage level is appropriate, given the nature of airport terminal processors.

A user under prevailing conditions of traffic and service at a subsystem perceives a state of the subsystem with a bundle of impacts (e.g., waiting time, processing time, congestion). For a given subsystem, the performance measures $pm_1, pm_2, \ldots, pm_q$ are defined. Table 4 shows such measures. For example, for the check-in area, performance measures include waiting time in the queue, processing time at the counter, and density of space use in the check-in area. In an attitudinal survey, users are asked to declare their preferences for each of the multiple performance measures, which can be transformed into relative weights.

For a design study, the facility size alternatives $a_1, a_2, \ldots, a_m$ result from the combination of level of service (and associated standards) and demand state (i.e., peak hour/period traffic). An alternative facility size will result in the occurrence of exactly one outcome state o, unknown beforehand, in a set of outcome states O, with elements $o_1, o_2, \ldots, o_k$. An outcome state consists of a bundle of impacts of various levels of performance attainment, pm_{gh}

TABLE 4 PERFORMANCE MEASURES FOR LANDSIDE FACILITIES: TERMINAL BUILDING AND APRON (*17, 18*)

Subsystem	Activities	Performance Measures
Apron/Gates	Aircraft circulation; parking and servicing; transfer of passengers, baggage and cargo	Service time, delays to aircraft, interference and congestion, queue length and waiting time
Baggage claim area	Processing of incoming, transfer, and outgoing baggage	Waiting time and queue length at baggage claim area, delay to aircraft, congestion, number of bags not transferred, number of outgoing bags not loaded
Entrance/exit	Airside processing	Queue length, waiting time, congestion
Boarding lounge	Entrance processing and storage	Queue length, waiting time, congestion
Security	Processing and storage	Queue length at entrance, waiting time, congestion
Customs and immigration	Processing and storage	Queue length at entrance, waiting time, congestion
Corridors and other links	Walking and circulation	Space per pedestrian, speed
Ticketing counter	Processing of passengers and baggage	Queue length, waiting time, congestion

TABLE 5 AIR TERMINAL BUILDING STANDARDS (SQUARE METERS PER OCCUPANT)

	Level of Service					
	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 (without device)	1.6	1.4	1.2	1.0	0.8	
Pre-PIL	1.4	1.2	1.0	0.8	0.6	

SOURCE: Transport Canada Standards.

(i.e., gth level of hth measure). Such impacts, revealed through an attitudinal survey of subsystem users, can be transformed into relative or utility numbers through the use of value functions. The individual or "pure" outcomes are combined by logical operations (by means of *and, not*) to form outcome states:

$$o_1 = pm_{11} \wedge pm_{21} \wedge \ldots \wedge\sim (pm_{12} \wedge pm_{22} \wedge \ldots) \wedge\sim (pm_{13} \wedge pm_{23} \ldots)$$

$$o_2 = \ldots$$

where

pm_{11} is the first level of performance measure 1,
pm_{21} is the first level of performance measure 2, etc.

The value functions are allowed to undergo the following linear transformations, which keep intact the performance achievement structure as perceived by users of the subsystem:

$$u_g(pm_{gh}) = y_g v_g (pm_{gh}) + b_g \qquad \text{for all } pm_g,\ g = 1, 2, \ldots, q$$

where

u_g = a numerical function on the gth performance measure,
$u_g(pm_{gh})$ = the transformed value of pm_{gh} (measured on a relative value scale),
$v_g(pm_{gh})$ = the original value of pm_{gh},
y_g and b_g = constants for criterion g.

The performance measures can be weighted and then combined:

$$U(o_j) = w_1 u_1 (pm_{1h}) + w_2 u_2(pm_{2h}) + \ldots + w_g u_g(pm_{gh})$$

where

$U(o_j)$ = the utility of outcome state j in relative value units—units measured on a scale of 0 to 1,
u_g = a numerical function on the gth performance measure,
w_g = a scale transformation parameter on u_g—a relative "weight" reflecting user preferences for measures of effectiveness (obtained from the strengths of preferences expressed as rank numbers).

To allow planners and designers the opportunity to use their subjective judgment of the occurrence of an outcome state o_j, a conditional probability distribution $p(o_j \mid a_i, d_\iota)$ can be used that expresses the planner's assessment of the conditional probability of the occurrence of outcome state o_j in O under the facility size alternative a_i and demand state d_ι combinations. The need to express such subjective judgments is clear since technical developments (e.g., machine-readable tickets/passports) and innovative procedures may change the existing relationships between throughput and performance of a subsystem (*19, 20*). The p's are assigned so that all but a finite o in O have $p = 0.0$, and the sum of the p's equals 1.0 for the subsystem size alternative-demand state combination.

For a given demand state d_ι, the utility of an alternative can be computed as:

$$U(a_i, d_\iota) = \sum_{j=1}^{k} p(o_j \mid a_i, d_\iota) U(o_j)$$

where $U(a_i, d_\iota)$ is the utility of size alternative i and demand state ι for $i = 1, 2, \ldots, m$ and $\iota = 1, 2, \ldots, n$.

The likelihood of the occurrence of demand states can now be treated as a variable. Let $P(d)$ be the planner's probability of a proposition that d_ι is the true state of demand. The expected utility of an alternative a_i can now be given as:

$$U(a_i) = \sum_{\iota=1}^{n} P(d_\iota) \cdot U(a_i, d_\iota)$$

From surveys of users at selected subsystems and analyses performed in accordance with the preceding theory, user reactions to quality of service could be obtained. A semantic scale of 1 to 7 could be used for obtaining user reactions on subjective as well as objective performance measures. Appropriate descriptors could be used for holding areas, time (delay) for processors, and so forth. In addition to getting a rating for each attribute, the relative importance of the attributes could be obtained. Simultaneously, using video cameras, the density levels (i.e., number of occupants per unit area) could be developed. A survey and associated analysis result in a utility number (between 0 and 1) for the subsystem under known conditions. For the saturation case, the utility rating could be zero or nearly zero, corresponding to LOS E. The corresponding density index (d/c) or volume index (v/c) would be 1.0, and space/service factors such as space/occupant and time spent in the subsystem could be found.

Likewise, for the various conditions of traffic studied, ranging from low traffic to very high usage levels, plots of utility against space use and utility against time levels could be developed. These are expected to show breaks reflecting thresholds. From threshold levels (breaks in the utility curve), LOS transition from E to D and from D to C could be found (Figure 2). In the absence of well-pronounced breaks, the planner and the airport authority can divide the utility axis into LOS ranges.

Figure 2 shows a utility function that exhibits the properties of diminishing marginal utility (value) (*16*). It can be seen that under congested conditions (e.g., LOS E), reduction in delay would result in relatively large gains in the utility (value) of users compared to less congested conditions, such as those experienced during LOS B or even LOS C. Also, it can be seen that there are certain threshold levels of delay that, when eliminated, result in substantial gain in utility.

The interrelationship of the level of service, density, or space indices and space standards is illustrated in Figure 3 for two selected processors. Also shown in this diagram is the influence of the sector (i.e., domestic vs. international) in terms of duration (i.e., up to 15 minutes, more than 15 minutes) on the level of service. For instance, a subsystem that experiences a *v/c* ratio of 0.75 for less than 15 minutes (as may be the case with domestic service) would be offering a level of service D. On the other hand, if duration exceeds 15 minutes, the LOS should be regarded as E (Figure 3).

Experience in Canada suggests that larger airports involve higher occupancy times because of such factors as airport access distance/time, reliability of access to airport services, airline requirements, and so forth. When applying LOS criteria in planning and design, in the absence of actual survey data, estimated *v/c* ratios should be considered for durations exceeding 15 minutes at a time. Subject to detailed studies, larger airports with a higher percentage of long-haul flights should offer more space per passenger than smaller airports. Of course, as can be noted in Figure 3, any processor operating above LOS C (i.e., LOS A and B) should be able to operate throughout a 24-hour period at these levels of service.

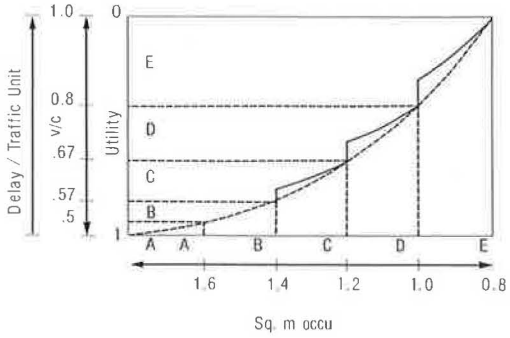
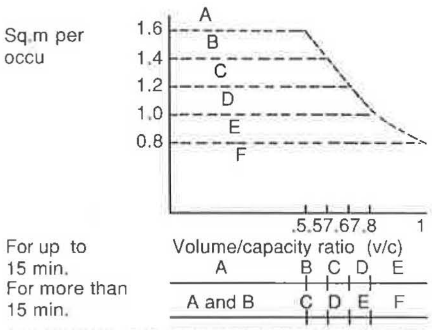


FIGURE 2 Level of service and utility: check-in and baggage claim.



Note: Sq. m/occu. correspond to Transport Canada's new space standards.

FIGURE 3 Level of service and space standards: check-in and baggage claim.

Finally, as noted earlier, technical developments are likely to increase processing rates and reduce airport occupancy times in the future. This means that space standards should be revised. For medium- and long-range planning, such advances should be assessed. Technological innovations and operational means that are likely to change the interrelationship of level of service and space or facility standards of landside subsystems include self-service check-in systems, machine-readable tickets and passports, new methods of enhanced security and improved throughput, and increased use of moving belts and people movers.

COST-EFFECTIVENESS OF DESIGNS

The optimal facility size and therefore the associated LOS can be established by using a number of methods for decision making under uncertainty. These are the expected value approach (based on use of the Laplace criterion of equal likelihood of the occurrence of demand states or other subjective probabilities), the Horowicz method (based on use of an index of optimism), the regret approach, and the criteria of minimin and minimax. These approaches are described in most engineering economics, operations research, and systems analysis textbooks.

In the event that the planner prefers to work with cost matrices, the expected overall cost of an alternative can be found as:

$$\text{Expected} \quad C^*(a_i) = \sum_{\iota=1}^{n} P(d_\iota) \cdot C(a_i, d_\iota)$$

where

$P(d_\iota)$ = the probability of the occurrence of demand state d_ι, and

$C(a_i, d_\iota)$ is the cost of facility size alternative i and demand state ι for $i = 1, 2, \ldots, m$ and $\iota = 1, 2, \ldots, n$.

The alternative with minimum expected social cost is the optimal alternative. Alternatively, the analysis could be carried out by working with savings of costs (i.e., benefits) through an incremental net value method. The level of service that corresponds to the optimal alternative is the best one for facility design.

Figure 4 illustrates the identification of the optimum number of gates by minimizing the present worth of total costs. Expected social costs were estimated under three demand states (i.e., growth rates). Level of service designations are noted that represent various degrees of delays to the airlines and passengers. As for capacity expansion decisions, Figure 5 shows that subjecting users to congested

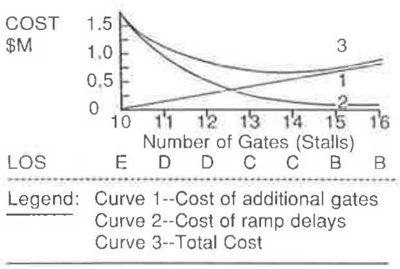


FIGURE 4 Facility size, cost, and level of service.

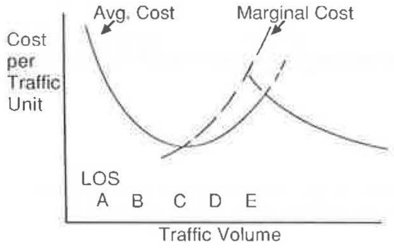


FIGURE 5 Capacity expansion at LOS E.

conditions associated with LOS E prior to capacity additions would be uneconomical owing to the unacceptably high cost of congestion.

CONCLUSIONS

This paper has demonstrated that a utility theoretic approach can be used to estimate the utility or user-perceived value of levels of service for landside subsystems, and to establish corresponding density or volume indices and space/service standards. It has also illustrated a methodology for assessing the cost-effectiveness of various levels of service and associated facility sizes within the uncertainty of future travel demand. The methodology can also be used to establish the most cost-effective level of service and optimal facility size.

The level of service framework based on LOS A to F is the most appropriate one for airport landside facilities. The most cost-effective LOS for the design of landside facilities is LOS C. LOS D could be used as the trigger point for capacity additions. Operations at LOS E are uneconomical from a "social cost" viewpoint.

The methodological framework advanced herein provides a mechanism for incorporating changes in the interrelationship of the level of service, density or volume indices, and space standards. Such changes are expected to occur as a result of technological developments and operational innovations that have the potential to change processing rates and throughputs of landside facilities.

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