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Effects of Ancillary Actvities on Passenger Flows in Airport Terminals

空港廳舍의 附帶施設이 旅客動線에 미치는 影響

朴 昌 浩*

(서울工大 土木工學科 副敎授)

目 次

要 約

空港의 容量測定은 需要群의 흐름에서 發生하는 消費時間分析을 要求하며 空港體系의 大部分 施設에서는 흐름의 時間變位를 連續待機列에 依한 非確率的方法으로 豫測할수도 있으나 廳舍內의 旅客動線에 대해서는 여러 施設을 活用하려는 旅客의 選擇選好로 因하여 確率的接近이 바람직하다. 本 論文은 空港의 廳舍內에서 附帶施設에 依하여 消費되는 旅客의 弛緩時間을 豫測하는 模型을 開發하였다. 總弛緩時間은 旅客이 各 施設을 利用하는 確率과 利用時間의 期待値에 대한 函數로서 計算되었으며 定常的인 旅客의 動線이 이들 施設에 依하여 影響을 받는 경우에만 定義되도록 하였다. 이 弛緩度는 連續된 廳舍의 機能施設에 對한 旅客動線分布의 入力과 出力을 說明하는데 쓰이게 되며 나아가서는 廳舍全般의 容量算定을 위한 指標를 提供한다. 模型 檢證을 위한 資料는 賣票臺와 保安檢査臺 사이의 附帶施設을 中心으로 蒐集되었으며 資料의 特性과 模型의 心要性이 論議되었다.

I. Introduction

To evaluate overall airport capacity, it is necessary to analyze airport component capacities simultaneously. One way is to treat successive components as tandem queueing mechanisms in which component inputs are expressed as functions of the outputs of preceding components.

This paper is concerned with the passenger terminal building subsystem of the airport system. Special attention is given to pairs of successive components between which there are ancillary

* 本學會 正會員・工學博士

activities. The major objective is to quantify the effect of intervening activities on passenger flows and on the arrival rates at subsequent components. A model is postulated for estimating the passenger dwell time affected by these activities. The total dwell time is computed by estimating a probability and an expected dwell time associated with joining each of the intervening activities. This total dwell time has application in expressing the input to a component as a function of the outputs of the preceding components in cases where ancillary activities affect this output/input transformation.

Data were collected on passenger flows through ancillary activities between the ticket counter and security check by using a technique called the "flash-card method," which is concerned with examining the number of passengers who utilize various intervening ancillary activities and the duration of their use as a function of the time remaining before their airline departure time. A discussion is presented of the salient features of these data.

It is attempted below to explain passenger behavior in terms of the non-deterministic time shift which allows a time lag when there exists a enough length of slack along their flow path. No previous attempt to do this was found in the literature.

II. Time Shifts of Passenger Flows

Consider a pair of successive airport processing components, j and j + 1, which are connected by a transport link, e.g., a corridor. It is desired to study the flow of passengers on a particular flight, say flight i, between the two components. After a passenger is dispatched from component j, he will arrive at the next component j + 1, a time later equal to the amount of time required to transfer from j to j + 1 if there are no delays or stops at ancillary activities. Under these assumptions, the input to one component of flight i passengers can be expressed as a function of the output of the preceding component by simply applying a uniform time shift as follows:

$$A_i^{(j+1)}(t + {}_j\tau_{j+1}) = G_i^{(j)}(t) \qquad (1)$$

where

$A_i^{(j+1)}(t)$ = cumulative number of arrivals of flight i passengers at component j + 1 by time t,
$G_i^{(j)}(t)$ = cumulative number of departures of flight i passengers from component j by time t.
${}_j\tau_{j+1}$ = transfer time from component j to j + 1.

Equation (1) implies that every flight i passenger has a uniform, deterministic transfer time and goes directly from component j to j + 1. Inside the terminal building, however, there are sets of component pairs between which there are optional ancillary activities such as restrooms, coffee shops, cocktail lounges that tend to randomize the order and uniformity of flow.

III. Postulated Model

One can expect a pause of flow between components j and j + 1 equal to at least the total expected amount of dwell time at the intervening activities. Equation (1) can conceptually be rewritten to take this into account as follows:

$$A_i^{(j+1)}(t + {}_j\tau_{j+1} + {}_jD_{j+1}) = G_i^{(j)}(t) \qquad (2)$$

where

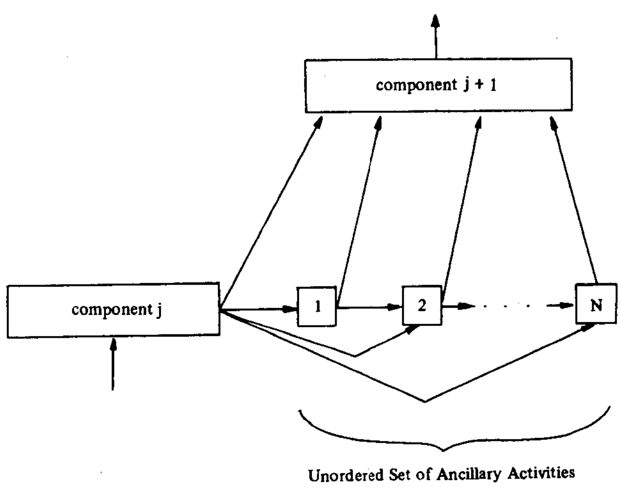
${}_jD_{j+1}$ = total expected dwelling time at ancillary activities between components j and j + 1.

A passenger on flight i, which takes off at time t_0, who is dispatched from component j at time t, has available time $(t_o - t)$ for passing through the remaining components and boarding his flight. It is assumed that he may allocate some of this available time to various ancillary activities depending on the magnitude of $(t_o - t)$. He may, for example, go directly to component j + 1 if $(t_o - t)$ is small, or he may spend time at one or more of the ancillary attractions for larger $(t_o - t)$.

A person leaving component j chooses between: (1) going directly to component j + 1, and (2) joining one or more of the N possible ancillary activities and then going to component j + 1. If he chooses to join an ancillary activity, he will subsequently be again faced with the choice of going to component j + 1 or joining another ancillary activity. This serial-choice concept is graphed in Fig. 1.

Let T be a random variable representing the total time between leaving component j and joining component j + 1, and let D_k be the expected dwell time at ancillary activity k, k = 1, 2, ..., N.[1] The

Fig. 1. Schematic of Passenger Choice of Ancillary Activities.



1) The random variable T will be shown to be a function of available time (t_0-t). A more precise notation would be $T(t_0-t)$ but the term in parentheses is left off for simplicity.

total time shift between components is assumed to consist of the minimum transfer time plus the sum of expected dwell times at ancillary activities plus the time spent going between ancillary activities. To estimate this total time shift, one can compute expected values of dwell times conditioned on the activities that a passenger visits. The minimum transfer time and times between activities are assumed deterministic and easily obtainable.

Let X_1 denote the first choice the person makes after leaving component j, $x_i = \{j+1, k, k=1, 2, ..., N\}$. Choice X_1 may be component j + 1 or any of the N intervening activities with probabilities $P\{X_1 = j+1\}$ and $P\{X_1 = k\}$; k = 1, 2, ..., N, respectively. Then, by conditioning on the choice X_1, we can write the expected value of T as

$$E\{T\} = E\{T \mid X_1 = j+1\}P\{X_1 = j+1\} + \sum_{k=1}^{n} E\{T \mid X_1 = k\}P\{X_1 = k\}$$

or

$$E\{T\} = {}_j\triangle_{j+1} P\{X_1 = j+1\} + \sum_{k=1}^{n} E\{T \mid X_1 = k\}P\{X_1 = k\} \quad \ldots\ldots\ldots\ldots \quad (3)$$

A person's total time shift also depends upon his second choice. By conditioning on the activity, he chooses second, X_2, one can expand the second term on the right-hand side of Eq. (3) to read:

$$\sum_{k=1}^{n} E\{T \mid X_1 = k\}P\{X_1 = k\} = \sum_{k=1}^{n} \sum_{X_2} E\{T \mid X_1 = k, X_2\} P\{X_1 = k, X_2\} \quad (4)$$

The right side of (4) can be further broken down into two portions: the first, corresponding to going directly to component j + 1, and the second to joining still other ancillary activities. If Eq. (4) is expanded for all possible combinations of ancillary activities and substituted back in Eq. (3), the resulting expression for the total expected time shift is:

$$\begin{aligned} E\{T\} = {} & {}_j\triangle_{j+1} P\{X_1 = j+1\} \\ & + \sum_{k=1}^{n} ({}_j\triangle_k + D_k + {}_k\triangle_{j+1}) P\{X_1 = k, X_2 = j+1\} \\ & + \sum_{k} \sum_{k+1} ({}_j\triangle_k + D_k + {}_k\triangle_{k+1} + D_{k+1} + {}_{k+1}\triangle_{j+1}) P \\ & \{X_1 = k, X_2 = k+1, X_3 = j+1\} + \sum_{K} \sum_{K+1} \sum_{K+2} \quad \ldots\ldots\ldots\ldots \quad (5) \end{aligned}$$

Note that the terms ${}_k\triangle_{j+1}$, and ${}_k\triangle_{k+1}$, and ${}_{k+1}\triangle_{j+1}$ represent transfer times involving ancillary activities.

The first term of Eq. (5) corresponds to going directly to component j+1. Each succeeding term, say the m^{th} term, corresponds to visiting (m-1) ancillary activities.

As stated earlier, although the time shift of a person might be a function of his available time in Eq. (5), the transfer times are considered constant. Furthermore, it is assumed that: (i) split probabilities are time-dependent and are decreasing functions of $(t_o - t)$, i.e., of available time (see

Figure 2. Stimulus Response Representation of Probability that Passengers go Directly to jtl.

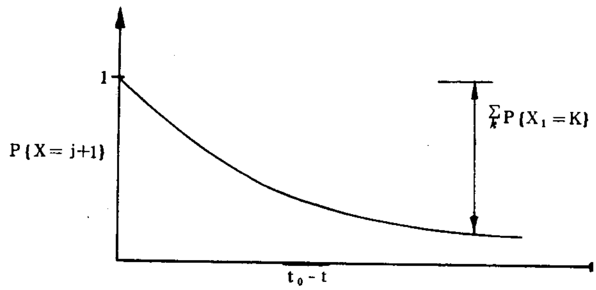


Fig. 2); (ii)1 $- P\{X_1 = j+1\} = \sum_k P\{X_1 = k\}$; etc., and(iii)the dwell time at each activity is independent of the order in which passengers use the ancillary activities and also independent of available time.

Since one can always write

$$P\{X_1, X_2, ..., X_n\} = P\{X_1\} P\{X_2 \mid X_1\} .... P\{X_n \mid X_1, ..., X_{n-1}\} \quad (6)$$

the split probabilities can be expressed as functions of the available time and related to each other using functional notation. Denoting

$$P_{j+1} = P\{X_1 = j+1\}, P_k P_{(k, j+1)} = P\{X_1 = k\} P\{X_2 = j+1 \mid X_1 = k\}, \text{etc.}$$

one can write the probability terms in Eq. (5) as follows:

$$P\{X_1 = j+1\} = P_{j+1}(t_o - t)$$

$$P\{X_1 = k, X_2 = j+1\} = P_k(t_o - t) P_{k, j+1}(t_o - t - {}_j\Delta_k - D_k - {}_k\Delta_{j+1})$$

$$\vdots \quad (7)$$

One can greatly simplify and reduce the task of estimating split probabilities by assuming that a person's probability of joining a particular activity is governed only by his available time, independent of which activities he has already visited or will visit after the activity in question. This assumes that there is one probability function, of the form of Fig. 2, that governs passengers' ancillary activity choices, i.e.,

$$P_{j+1}(t_o - t) = P_{k, j+1}(t_o - t)$$
$$= P_{(k, k+1), j+1}(t_o - t) = \quad (8)$$

and

$$P_k(t_o - t) = P_{k-1,\,k}(t_o - t)$$
$$= P_{(k-2,\,k-1),\,k}(t_o - t) = \ldots$$

Note that the probability function of Fig. 2 can be viewed as a simple stimulus-response relationship; the stimulus is available time and the response variable is the probability that a passenger joins an ancillary activity (any one) before going to component j + 1.

Equation (5) can now be rewritten to include the simplifications of Eq. (8) as follows:

$$E\{T\} = {}_j\triangle_{j+1} P_{j+1}(t_o - t) + \sum_k ({}_j\triangle_k + D_k + {}_k\triangle_{j+1}) P_k(t_o - t) P_{j+1}(t_o - t - {}_j\triangle_k - D_k - {}_k\triangle_{j+1})$$
$$+ \sum_k \sum_{k+1} \ldots \ldots \quad (9)$$

Given a transfer time matrix, dwell times for ancillary activities, estimates of the initial split probabilities from component j, and the stimulus-response relationship of Fig. 2, one can estimate the total expected time shift between components j and j+1 using Eq. (9). Notice that by Eq. (9) a passenger is not prohibited from visiting the same ancillary activity more than once as long as his available time permits.

Suppose that there are $G_i^{(j)}(t)$ flight-i passengers released from component j by time t. If one assumes that all passengers are homogeneous, i.e., that their split behavior is identical, and that all passengers take exactly $E\{T\}$ to go from component j to component j+1, one can estimate the input distribution of component j+1 as

$$A_i^{(j+1)}(t + E\{T\}) = G_i^{(j)}(t) \quad \ldots \ldots \quad (10)$$

Equation (10) transforms an output from component j into an input to component j+1 considering the effects of ancillary activities.

The foregoing model development has been for originating passengers. The same principles can be applied to transfer passengers by identifying component pairs between which transfer-passenger flow is affected by ancillary activity usage. Note, however, that the model is not adaptable to deplaning passenger flows because the concept of available time would not apply. Besides ancillary activity usage probably does not significantly affect the deplaning flows.

IV. Validation of the Model

The major assumptions of the model are tested using data collected at Robert Mueller Municipal Airport in Austin, Texas and Oakland International Airport in Oakland, California. Also described below is the data collection technique. Furthermore, model estimates of input patterns to components located beyond the ancillary activities area are compared with actual observations of those patterns.

Data Collection – The Flash-Card Technique. The "flash-card" method was devised to study the usage of ancillary activities inside a terminal building. The objective was to observe the number of trip makers who utilize ancillary activities and their duration of usage as a function of the time remaining before their flight departure, and to observe the times at which passengers arrive at components located beyond the intervening activities.

The survey technique involves tracing passenger and visitor movements through the terminal building. Briefly, the technique works as follows: each enplaning passenger and related visitor is handed a numbered card as he enters the terminal building, his flight number is recorded, and he is asked to show or flash the card at designated survey stations located at key points within the terminal building. At each survey station, card numbers and times at which persons pass the station are recorded by observers for each 1-minute or 30-second time interval. Finally, the card is collected as the passenger or visitor leaves the survey area, either at boarding lounges, security checks, or at the exit doors. Note that, except at the entrance doors where the cards are disbursed, there is no verbal contact with, nor interruption of, passenger and visitor flows. The three basic elements of the flash-card survey: card distribution, recording of card numbers of 1-minute or 30-second time intervals, and card collection are described in detail by Park (4).

This flash-card method was adapted from the time-stamping technique proposed by Braaksma (2, 3). Its principal advantages over Braaksma's method are that less expensive equipment (stop watches versus time-stamping machines) is used and that there is less interference between passengers and surveyors. Braaksma's method, on the other hand, produces data which are (1) more amenable to subsequent analysis (2), discrete event times rather than events by time slices, and (3) less subject to recording errors. For purposes of this research, the advantages of the flash-card method were considered to outweigh its disadvantages.

An initial survey using the above technique was conducted at Robert Mueller Municipal Airport in Austin, Texas from 12:15 p.m. to 4:15 p.m. on 4 June 1976. This airport is well suited for this initial study, because nearly all its ancillary intervening activities lie between the ticket counter and security check. The Austin survey was preliminary in that its objective was in part to test public acceptance of the flash-card technique and its impact on terminal operation. The survey results indicated that people were willing to cooperate and the impact of the survey on normal traffic flows was negligible. During this survey a 94 percent card return rate (344 cards from a total of 368 cards distributed) was obtained for eight scheduled flights of three airlines.

In the same year the next survey was performed at San Antonio International Airport in Texas. The data gathering and results of the analysis turned out to be quite successful. For this paper, however, the same survey was conducted on 5 September 1983 at Oakland International Airport. The purpose of this recent survey was to check whether the passenger behavior has been changed during the past several years. In the Oakland survey, a total of 845 cards were distributed and 622 were collected, a 74 percent card-return rate, for 15 scheduled flights of 6 domestic airlines.

Listed in Table 1 are the ancillary activities surveyed at the two airport terminal buildings.

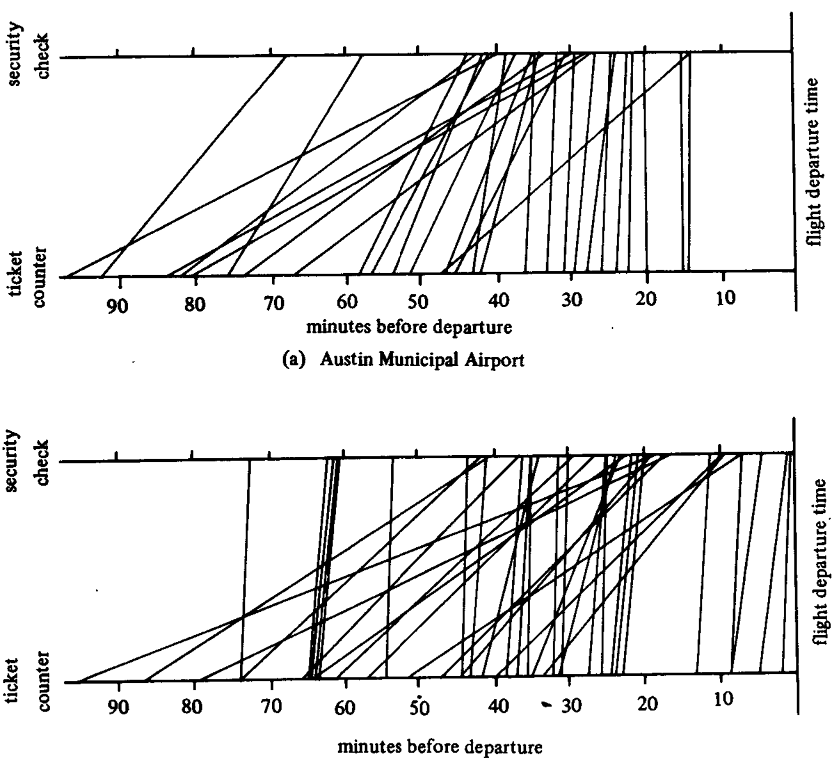
An attempt was made to distribute as many cards as possible during the two surveys. Although the data provide a fairly complete account of travel patterns of card-holders inside a study area, it was decided that, except for one or two or three large flights, the number of data points is not large enough for the analysis on an individual flight basis. Thus, in some cases below, the data are treated on an aggregate basis; the implied assumption is that passenger and visitor behavioral characteristics are independent of individual flights.

Only passengers for domestic flights were surveyed. Behavior of international flight passengers probably differs from that of domestic passengers.

Table 1. Ancillary Activities at the Two Airport

Austin Airport	Oakland Airport
restaurant	restaurant
gift shop	gift shop
restrooms	restrooms
telephone-booth area	telephone-booth area
vending-machine area	lounge

Fig. 3. Arrival Times at Two Successive Components of Individual Persons.



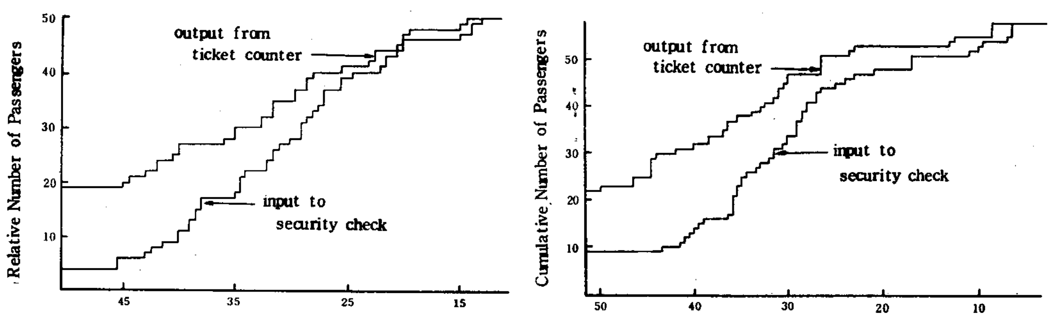
(a) Austin Municipal Airport

(b) Oakland International Airport

Test of Model Assumptions. Shown in Fig. 3 (a) and (b) are individual trajectories of different persons traveling between the ticket counter and security check for two selected flights, one at Austin and one at Oakland. The lower scales in each figure indicate departure times from the ticket counter while the upper axes stand for input times to the security check; lines with flat slopes indicate persons using intervening activities; steep slopes represent persons going directly from the ticket counter to the security check; different flat slopes correspond to different numbers of ancillary activities visited.Note the apparent congestion at the security checks around 30 to 40 minutes before the flight departure times and that this congestion is obviously greater than what would have occurred if all persons had gone directly to the security check. This is why it is important to analyze ancillary activities.

Shown in Fig. 4 (a) and (b) are observed time shifts between a pattern of output from the ticket counter and the pattern of input to the security check for same flights as in Fig. 3. Note that the total dwelling time of a passenger, E{T}, is represented by the horizontal difference between the two curves (recall from footnote 1 that T is a function of available time). From the figures it is apparent that the longer the available time before a flight, the greater the total time shifts.

Fig. 4. Cumulative Arrival Curves at Two Successive Components.



(a) Time Shift of Flow for Flight A at Austin. (b) Time Shift of Flow for Fight B at Ookland

Recall that there were two basic assumptions concerning the model:

(1) dwell times are independent of available times, and

(2) given the same amount of available time, the probability that a person joins the security check or any particular intervening activity is the same regardless of which activities he has already visited.

The validity of these assumptions is tested below:

Dwell Time Versus Available Time. Dwell time is the time spent by a passenger at an intervening activity. From the data, observed dwell times were plotted against available times. It was found that dwell times can be assumed independent of available times. Evidence on this independence question was obtained by arranging dwell-time vs. available time data on restaurants and gift shops at the two airports in two-way contingency tables and applying Karl Pearson Chi-Square tests of independence to test the hypothesis that dwell times and available times are stochastically independent. From the data, there was no reason to believe that dwell times and available times are not independent [see Park (4) for details].

Probability of Joining the Security Check. It is desired to test the assumption that the split probability of going directly to the security check from any intervening activity is the same as that from the ticket counter given the same amount of available time. Let P_i and Q_i be split probabilities of joining the security check from the ticket counter and after visiting one intervening activity, respectively. The hypothesis that $P_i = Q_i$, for all i, was tested using the two sets of data collected at Austin and Oakland airports. As noted previously, data are treated on an aggregate basis in that all surveyed flights are combined to calculate these probabilities, except for one flight departing at Oakland airport.

The probability Q_i is calculated based on passengers who go directly to the security check after visiting exactly one intervening activity. The split probabilities after two or more intervening activities were not obtained because there were too few data points for these cases for a reasonable analysis. The procedure for testing the similarity between the split probabilities, P_i's and Q_i's, was to fit theoretical probability distributions to the observed values and then to compare estimated parameters of those distributions.

It has been assumed in this research that the decision process of joining the security check vs. joining ancillary activities is analogous to a stimulus-response process. The stimulus is the amount of available time and the response is whether or not a passenger elects to go directly to the security check. It has been found in a variety of applications, e.g., bio-assay, that the probability of a response as a function of the strength of stimulation can be approximated satisfactorily by a cumulative normal distribution, i.e.,

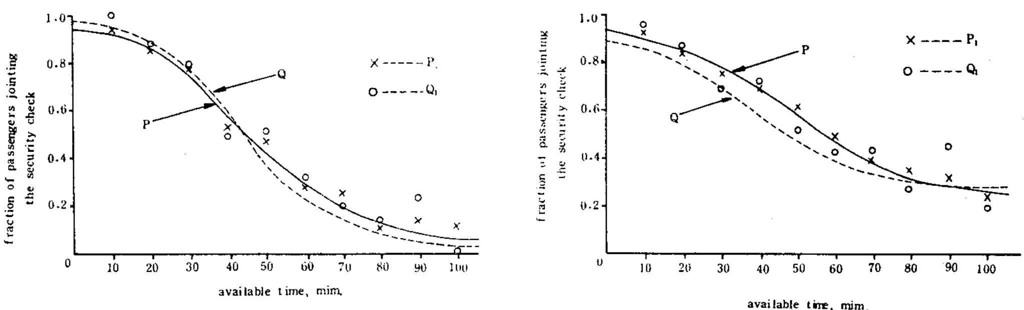
$$P_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\alpha + \beta\delta_i} e^{-\frac{Y^2}{2}}\, dy \qquad (11)$$

This kind of relationship also holds for Q_i. Notice that P_i is the cumulative normal probability distribution function corresponding to the standard normal deviate $\alpha + \beta\delta_i$.[2] Berkson's Normit analysis was used to obtain estimates α and β (1). These estimates have excellent small sample properties, such as the smallest mean square error (smaller than that of the maximum likelihood estimates or the minimum Chi-Square). To check the normality assumption, the classical Chi-Square goodness-of-fit tests were applied. The results of this analysis are shown graphically on Fig. 5 (a) and (b) for Austin and Oakland data,respectively. From these test results, it was concluded that split probabilities may be assumed to follow a cumulative normal distribution.

Finally the hypothesis that the P_i's and Q_i's are identical for every time interval was tested; this involved testing the hypothesis that there is no difference between the parameters for these two probabilities. The restricted Chi-Square test by Neyman was adopted to test this hypothesis using the Austin and Oakland data. The results suggested that, at each airport, split probabilities from intervening activities can be replaced by those from the ticket counter, i.e., that $P_i = Q_i$ for all i. It is also suspected that passenger split behavior is independent of individual flights, although this could not be tested.

2) This normal deviate has been called the Normit which involves the transformation of normal sigmoid cures into straight lines (Ref. 1).

Fig. 5. Normal Curve Fitting by Berkson Normit Analysis.



(a) Cumulative Normal Approximations of Split Probabilities Observed at Austin Airport.

(b) Cumulative Normal Approximations of Split Probabilities Observed at Oakland Airport.

Probability of Joining Ancillary Actvities. It was also desired to test the hypothesis that the split probability of joining a certain ancillary activity from any other ancillary activity is identical to that from the ticket counter given the same amount of available time. Again by assuming the stimulus-response process for joining the ancillary activities, tests are performed similar to those described in the previous section. Results of the tests indicated that the hypothesis should not be rejected.

Estimation of Subsequent Flow Patterns. It was attempted to apply the model of Eqs. (9) and (10) to estimate input flow patterns at the security check from the output patterns of previous components. The scope of this estimation was limited in that only passenger flows dispatched from the ticket counter were considered. To estimate the total expected time shift, E{T}, three major inputs were used:

(1) transfer time matrices,
(2) dwell time at each individual ancillary activity, and
(3) split probabilities.

Table 2. Transfer time matrices for the two airports

From \ To	Vending Machine	Telephone	Gift Shop	Restroom	Restaurant	Security check
ticket counter	1.1	1.2	1.5	1.9	2.1	2.2
vending machine		0.1	0.3	0:8	1.1	0.8
telephone			0.2	0.7	0.9	0.9
gift shop				0.4	0.6	1.2
restroom					0.7	1.6
restaurant						1.4

(a) Transfer Times at Austin Airport, min.

From \ To	Lounge	Telephone	Gift Shop	Restroom	Restaurant	Security Check
ticket counter	3.5	2.7	2.8	2.7	3.1	3.9
lounge		1.7	0.6	1.7	0.6	0.3
telephone			1.2	0.2	1.2	2.3
gift shop				1.1	0.4	0.8
restroom					1.2	2.0
restaurant						0.8

(b) Transfer Times at Oakland Airport, min.

Shown in Table 2 are the transfer-time matrices for each airport computed from the geometric configurations of the terminal buildings and observed mean walking speeds; it is interesting to note that transfer times are considerably higher than the given distances divided by commonly used pedestrian walking speeds of 3.5 to 4.0 ft/sec. The observed mean walking speeds were 2.1 ft/sec. and 2.7 ft/sec. for Austin and Oakland passengers, respectively.

The dwell times at individual intervening activities are listed in Table 3. Dwell times were used as if constant for the estimation of demand patterns.

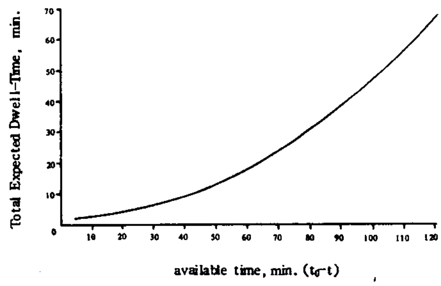
Table 3. Dwell times at intervening activities.

	Austin Airport		Oakland Airport	
	Mean	Standard Deviation	Mean	Standard Deviation
restaurant	23.67	13.37	22.84	11.62
gift shop	3.86	3.30	3.91	6.42
restroom	3.02	3.15	2.69	2.64
telephone	5.15	4.67	4.40	3.51
vending	1.64	0.92	–	–
lounge	–	–	12.41	12.88

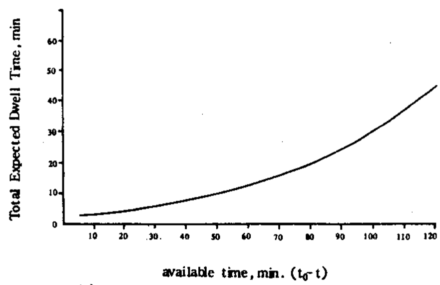
The total expected time shifts were calculated by the use of Eq. (9) and these are graphed in Fig. 6. As shown, the total expected dwell time is a convex function of the available time. The time shift at Oakland Airport is less than that at Austin Airport. This difference is probably due to the existence of another set of ancillary activities beyond the security check at Oakland Airport.

The foregoing estimated time shifts were applied to observed output curves from the ticket counter in order to estimate input patterns to the security check. Two individual flights were used for demonstration. Figure 7 (a) and (b) show comparisons of estimated input patterns versus actual observed patterns at Austin and Oakland, respectively. The result shows that the model can predict the subsequent input patterns reasonably well. The model, however, exhibits a general tendency of understimating the total time shifts. This is probably due to persons who linger between ancillary activities or who use activities not identified in the model.

Fig. 6. Total Expected Time Shift as a Function of Available Time.



(a) Total Expected Dwell Time at Austin Airport.



(b) Total Expected Dwell Time at Oakland Airport.

Fig. 7 (a). Estimated and Observed Input Patterns at Austin Airport.

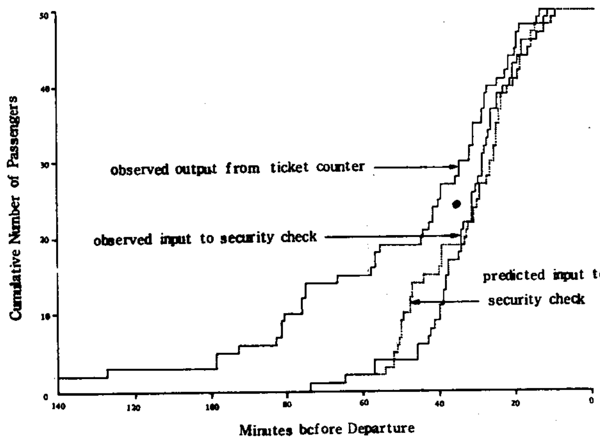
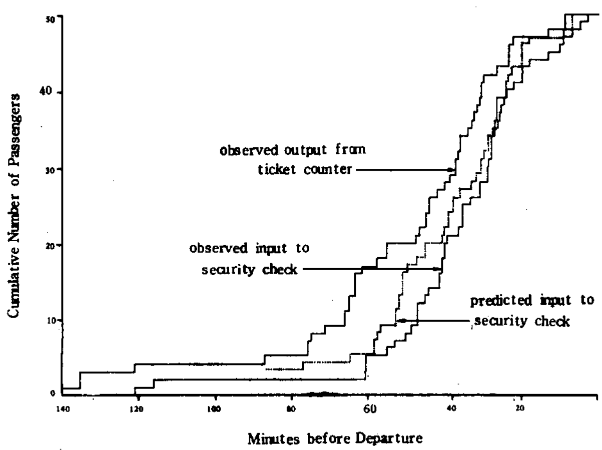


Fig. 7 (b). Estimated and Observed Input Patterns at Oakland Airport.



V. Discussion

The effects of ancillary activities on airport passenger flows have not, to the writer's knowledge, been considered in any previously-reported analytical methods for estimating passenger flow patterns and delays at successive airport components. It is probable that, in most cases, their effects are minor compared to the influence of the major processing components on the overall quality of service provided to airport users. Nevertheless, it is recommended that the effects of ancillary activities be estimated using the methods of this paper for the following reasons:

(1) it is difficult, a priori, to evaluate the potential effects of the ancillary effects on congestion and arrival times at downstream components, e.g., Fig. 3.

(2) the methods contribute to the completeness of an overall analysis of passenger and visitor flows through terminal buildings by providing an approximate link between sets of components that straddle ancillary activities;

(3) the model of this paper could be adapted for use in testing the impacts of alternative locations and configurations of ancillary activities on the congestion and delays experienced by the main-stream of passengers and visitors; thus, it could be an aid in evaluating alternative terminal building designs.

VI. Conclusions

The following is a list of the major conclusions of this paper.

(1) Ancillary activities, because they affect the time shift and order of flow between successive components, may lead to congestion and bunching over and above what would be estimated by a simple tandem-queueing method under deterministic time shifts.

(2) The likelihood of joining ancillary activities is a decreasing function of available time; this function can be viewed as a stimulus-response relationship.

(3) Dwell times at ancillary activities can be assumed independent of available time.

(4) The proposed model can be used to obtain reasonable estimates of arrival patterns at components immediately beyond or downstream from the ancillary activities.

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