TRANSPORTATION RESEARCH RECORD

499

Formerly issued as Highway Research Record

Travel Demand, Mode Choice, and System Analysis

7 reports prepared for the 53rd Annual Meeting of the Highway Research Board

subject areas

15 transportation economics
84 urban transportation systems

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

Washington, D. C., 1974

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TRR 499
ISBN 0-309-02289-4
LC Cat. Card No. 74-17764
Price: $4.00

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FOREWORD

The papers in this RECORD examine various aspects of travel demand, mode choice, and system analysis. Transportation system planners should find these papers of significant interest.

The first paper summarizes the findings from an intensive on-board survey conducted by the Metropolitan Atlanta Rapid Transit Authority during November 1972. The study examines some of the questions generated after transit fares were reduced from 40 cents to 15 cents, including the magnitude of the increase in ridership and its distribution between new transit riders and additional tripmaking by previous riders, the magnitude of diversion from automobile use, and the characteristics of new and old riders.

The second paper investigates the potential for gradually restructuring urban areas to reduce the built-in requirements for transportation. The authors analyze transportation requirements of some alternative urban spatial structures and develop a computer-directed search procedure. These experiments form the basis for an investigation of a larger urban structure based on the 1970 urban pattern of western King County, Washington. The results of these investigations indicate that by moving about one-third to one-half of the people and about one-third of the jobs to other locations, substantial reductions (50 percent or more) in travel requirements could be obtained while overall access levels are improved.

The third paper examines the internal relationships between the socioeconomic characteristics of commuters and the transportation service characteristics they value in their choice of mode for work trips. The study is specifically concerned with (a) correlation of selected socioeconomic factors of individuals with their choice of travel attributes and (b) the effect of socioeconomic factors in causing car drivers to shift modes. Canonical correlation analysis illustrates that each modal group using a transportation corridor has unique socioeconomic characteristics and that these are related to the attributes of the transportation system. Statistical tests using discriminate analysis on a subsample of automobile drivers indicate that the socioeconomic characteristics of an individual probably exert an influence on his tendency to shift mode and his sensitivity to specific transportation service level changes in the system. In particular the author found that as income levels increase the tendency to shift mode decreases. The findings of the study have implications for mode split planning, travel demand modeling, and urban structure.

In the next paper the authors report on ground transportation characteristics of passengers using the Air-Shuttle services provided at LaGuardia Airport by Eastern Airlines. The research establishes relationships between characteristics of shuttle passengers, comprising about 15 percent of all LaGuardia enplanements, and those of other passengers using LaGuardia Airport and Eastern Airlines facilities. The data derived from field surveys have been analyzed relative to the impacts shuttle travelers have on the road system, parking facilities, and curb frontages at the terminal buildings. Results of this research support the assumption that shuttle passengers have parking durations about 50 percent less than other terminal passengers and their parking space demands are about 40 percent less than other system passengers.

The next paper examines the ground transportation congestion problem of 20 U.S. airports. Several broad problem areas are identified from this study: Origins and destinations of air travelers presently oriented to and from the airports are too dispersed to justify either rapid transit corridor or other main-line investment, and too much vehicular activity is concentrated at or near the enplaning and deplaning curbs in the terminal areas, which reduces effective capacity. The authors suggest that without capital-intensive projects the alternatives would best be the application of traffic engineering techniques to obtain more efficient use of existing roadways or to alter travel patterns and habits of air travelers so that more off-peak highway capacity would be used.

The next paper reports on a prototypical application of a new methodology called Special Area Analysis, designed to assess the quality of accessibility in metropolitan areas. In addition, the methodology is applied toward an evaluation of the level of accessibility afforded to specific population subgroups such as low-income and zero-car households. This study demonstrates that the SAA methodology is a useful evaluation tool for use by metropolitan area transportation planning agencies.

In the last paper the problem of integrating system and project planning to systematically include community and environmental concerns is discussed. The authors identify the major problems in the current system-project relationship, then discuss a philosophy for integrating the activities of these different levels of planning, and finally present some practical and implementable techniques for more effectively integrating system and project plans.

EFFECT OF FARE REDUCTION ON TRANSIT RIDERSHIP IN THE ATLANTA REGION: SUMMARY OF TRANSIT PASSENGER DATA

John W. Bates, Metropolitan Atlanta Rapid Transit Authority

This paper presents in summary form the findings from an intensive on-board survey conducted by the Metropolitan Atlanta Rapid Transit Authority during November 1972. On March 1, 1972, transit fares in Atlanta were reduced from 40 cents to 15 cents, with free transfers. Patronage immediately increased significantly and continued to increase as the Authority initiated implementation of service improvements as part of its short-range transit improvements program. The research was designed to answer specific questions generated after the ridership increase was observed, including the magnitude of the increase and the distribution of increase between new transit riders and additional tripmaking by previous riders, the magnitude of diversion from automobile users, and characteristics of new and old riders. This is one of a series of reports from the overall research effort, which includes the on-board study to determine rider characteristics as well as an in-home study to determine attitudes of nonriders and the reasons they do not use transit.

•ON February 17, 1972, the Metropolitan Atlanta Rapid Transit Authority took the first step in implementation of its short-range transit improvement program, which had been approved by referendum in Fulton and DeKalb Counties, Georgia. This first step was the acquisition of the privately owned Atlanta Transit System, Inc., which had been for many years the only significant supplier of public transportation services in the Atlanta Metropolitan Area. On March 1, 1972, the Authority took the second step in the short-range transit improvement program by lowering the fares on its recently acquired operating division from the previous 40-cent base fare with 5-cent transfer charge to a 15-cent flat fare with free transfers.

The reduction in fare was a part of the development of the Authority's overall financial planning. The primary income source for implementation of the $1.8 billion transit development program is a 1 percent sales and use tax levied in the two-county implementation district. To overcome the inequity of a sales tax, which is highly regressive, a policy of maintaining low fare levels was established, with both sales tax and fare revenues applied to meet development and operating costs.

Implementation of reduced fares had immediate and unanticipated effects. During the first week of reduced fare operation, ridership increased approximately 18.5 percent (based on fares and transfers received), compared to previous estimates for continued Atlanta Transit System operation at the prevailing fare. Ridership continued at an increased rate, and as a result the Authority was forced on an emergency basis to acquire used vehicles from other transit operations to be reconditioned and put into service to relieve overloads.

In subsequent weeks the Authority made other service changes with additional vehicles acquired on an emergency basis. Over the ensuing months ridership continued to grow,

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

and changes in service were provided within the limits of vehicle availability. Through November 1972, 117 separate changes were made that increased the annualized vehicle-miles of operation from approximately 19 million at the date of acquisition to approximately 22 million annual vehicle-miles of service. The service changes made were primarily in the area of improved headways and expanded service periods. There were 85 such changes; in addition, 13 lines were extended, 14 lines were revised, and 5 new lines were installed.

Some increase in transit patronage had been forecast to result from the fare reduction. This forecast was based on the traditional and time-proved marginal elasticity of fares in Atlanta, which indicated that, for increases or small decreases in fare, total volume would decline or rise approximately 0.25 percent for every 1.0 percent change in fare. Original estimates for ridership increase were on the order of 12 percent; this was significantly exceeded during the first week of reduced fare experience.

As the results of the Authority's experience with increasing ridership became known, many questions were asked by persons outside the Authority, as well as within the organization, as to the reason for this dramatic and unexpected growth in transit ridership. These can be reduced to five basic types of inquiry:

1. What is the increase in ridership? How much of the increase is due to reduced fare and how much is due to service changes?
2. How much automobile traffic has been diverted to transit? What mode of travel did new riders use before they changed to transit?
3. What are the characteristics of transit ridership now as compared to before MARTA? What are the differences between the old and the new riders?
4. How does the quality of service compare now with the quality before MARTA? What do transit riders think of the quality of service? What types of improvements do the riders want? Is there a difference between the types of service improvement that are desirable to new riders and those desired by old riders?
5. Did the fare need to be reduced as much as it was in order to achieve significant increases in transit ridership?

To answer these questions both for its own information and because of the strong national interest in the results of its program, the Authority, in cooperation with the Urban Mass Transportation Administration and as part of the Atlanta Regional Transportation Planning Program, undertook this research effort.

STUDY DESIGN

Beginning in April 1972 the Authority, with assistance from professional consultants, designed a two-part research effort to seek answers to these questions. The study consists of a survey of transit riders to determine their actual characteristics and patterns and an in-home interview survey to determine transit attitudes of those who did not ride. This report deals with the survey of transit riders.

Traditionally, surveys of transit riders are made through a "hand-out, mail-back" technique where interview cards are distributed to transit riders on a given day or series of days. The riders are asked to complete the cards and return them to a collection point on the vehicle or to mail them to a central collection point. This type of survey was conducted by the Authority in October 1970 as a part of its planning program to develop the short-range transit improvements program. However, for the purposes of this current research effort, it was felt that detailed and in-depth interviews would be necessary to determine characteristics of the riders and the reasons for their change to transit, if indeed they had changed their mode of travel. In-depth information is difficult to obtain through the hand-out, mail-back survey because the respondent must complete the information on a voluntary basis with little explanation and assistance. It was therefore determined that the research effort would best be accomplished through intensive interviews conducted in person with a small number of transit riders. With the assistance of consultants Alan M. Voorhees and Associates and Behavior Science Corporation, it was determined that a sample of approximately 3,500 transit riders would provide sufficient statistical reliability and that such a sampling process could be accomplished with reasonable expenditures of effort and funds.

It was decided that, to achieve a representative sample, it should be stratified into six time periods. Four of these time periods are within the normal weekday: the morning peak between 6 and 9 a.m., the midday or base period between 9 a.m. and 3 p.m., the afternoon peak period between 3 and 6 p.m., and the evening or balance of day from 6 p.m. until the termination of service and its resumption in the early morning hours prior to 6 a.m. Since transit ridership is small on the weekend in relation to the weekday, Saturday and Sunday in their entirety were each selected as a sampling period.

The survey was further stratified into market segments. All transit routes were classified into four major categories: those serving predominantly low- and middle-income residential areas, those serving predominantly middle- and high-income residential areas, those that could not be placed in either of those two groups, and those providing special types of services. Because several changes in service had been made during the preparation of the study, it was decided to further stratify each of these four classifications into two subclasses: those routes on which service had been changed and those on which it had not. After consideration of the estimated ridership volumes within each of the eight classifications, it was determined that the volumes in several were not sufficient for statistical reliability and the classifications were then recombined into four final classified groups:

1. Route type one—routes serving primarily low- to middle-income residential areas on which no service improvements had been made; domestic routes are also included;
2. Route type two—routes serving primarily low- to middle-income residential areas on which service improvements had been made, or the routes initiated;
3. Route type three—routes serving middle- to high-income residential areas; and
4. Route type four—all routes that had received the fare reduction not included in any category above; also includes mixed-income areas and/or business area service.

The number of special service routes (Shoppers Special, Town Flyer, Stadium Shuttle, school bus, and other similar services), their volumes, and the specific characteristics of these routes were such that they were excluded from the survey. Based on the percentage of total ridership estimated within each of these route classifications and time periods, the total number of interviews required (3,500) was divided proportionally into "survey cells".

Since a primary concern was determination of the number of new riders (i.e., those who did not ride transit regularly prior to March 1, 1972, the date of the reduced fare) and old riders (i.e., those who did utilize transit regularly prior to March 1, 1972) and, since the characteristics of the old and new riders were a basis of comparison, a separate questionnaire was developed for each of these "transit markets". Many identical questions were asked both new and old riders, but in some cases separate or specific questions relating to that market were asked.

In structuring the interview procedure it was decided that, if a respondent had changed his place of residence between the time of the fare reduction and the interview, then his or her response would be biased by the change in location and would not be in response to either the fare change or service changes that had taken place. Therefore, no interviews were conducted with persons whose residence had changed after March 1, 1972. The assumption was implicitly made that, had these persons been able to respond purely to changes in the transit system, then they would have responded in the same proportions as those who had not made a change in residence location.

The first question asked of a respondent was the locational question, "Did you live at the same address you are living now before March 1 of this year?" If the respondent replied negatively, the interview was terminated and the interviewer moved to the next respondent. The second question was, "Did you ride the bus regularly before March 1 when the fare was 40 cents?" Based on this response the interviewer then proceeded with one or two sets of questions.

Questions asked or observations made of both old and new respondents included the race and sex of respondent; the means by which they reached the vehicle; the number of transfers required if transfers were required; the means by which they would leave the vehicle to complete the trip and the number of transfers which would be required, if any; the origin and destination of the trip; determination if either origin or destination were at home; the purpose of trip; the number of automobiles owned by the family; whether the respondent was an automobile driver; if an automobile was available for the trip; the number of weekly transit trips made; the reasons for these trips; the perceived quality of service; the types of improvements desired; the age of the respondent; and the respondent's household income.

Questions asked only of "old" riders included whether the respondent made more trips now than previously, and the perceived change in service quality since the initiation of MARTA operation.

Questions asked only of new riders included the mode previously used for making the same trip or if the trip were not made previously; if the respondent would continue to use transit at a 25-cent fare, and if continuing to use at 25 cents would respondent still continue at a 40-cent fare.

An interview required 5 to 7 minutes to complete.

Before initiating the survey, which was conducted November 11 to 21, 1972, notice was given to transit riders through the newsletter "Two Bells", distributed on the buses, and through news releases to the media. On the first day of operation news media publicized the survey and in some cases television film interviews were made and telecast.

Approximately a 1 percent sample was taken, or one interview for every 100 riders. Interviews were clustered on selected routes throughout the specified time periods. The number of surveys required in each time period on each route type was compared with volumes on the higher volume routes within a classification or route type. Samples required within each route type and time period stratification were compared, along with the time required to conduct an interview and the run time of each route, and for each route and time period a sampling factor was determined. Sufficient routes were scheduled for interviews to result in a sufficient number of interviews to meet the original study design. A safety factor of additional interviews was also included to compensate for expected "bad" or incomplete interviews or interviews unusable for some other reason. The sample factor for each route varied within the area from one to ten. For example, with a sampling factor of seven, the interviewer interviewed each seventh person on the vehicle during his assignment period. After completing the survey the data were coded for machine processing. After editing the data some interviews were rejected, resulting in a total of 3,738 usable interviews. An expansion factor was then determined for each route and time period so that the interview data could be expanded to represent the entire transit ridership.

From the sampling techniques used, it is felt that the information derived from the survey is reliable and that the percentage distributions found are within 2 to 4 percent of true values, with confidence levels of at least 90 to 95 percent. These indications of statistical reliability are based on a standard assumption that the sample itself is a random sample. There is naturally no assurance that randomness is present. However, the purpose of stratification in the sampling procedure and computation of expansion factors by survey route and time periods, rather than using average or overall expansion factors, was to provide reasonable assurance that survey results were achieved within the designed reliability and confidence.

SUMMARY FINDINGS

As a result of analysis of the survey, those questions relating to transit ridership characteristics can now be answered.

Characteristics of Ridership Increase

The first questions needing answers were What is the increase in ridership? How much of the increase is due to reduced fare and how much is due to service changes? How much of the increase is due to new riders, and how much is due to more trips made by old riders?

Overall transit ridership increased 30.2 percent, with 91 percent of the increase due to new rider trips. On weekdays, the increase was 28.0 percent, due entirely to new rider trips. On Saturday transit ridership increased 41.0 percent, with over half of the increase (52.2 percent) due to new rider trips. The largest increase in ridership occurred on Sunday, where it is indicated to be 78.8 percent, with almost two-thirds (63.5 percent) of the increase due to increased tripmaking by old riders. The volumes of ridership developed from the survey within each of these classifications are given in Table 1.

When asked if the reason for their change to transit was fare, service, or other, half or more of all new riders responded fare (56.2 percent of weekday new riders, 49.3 percent of Saturday new riders, and 53.1 percent of Sunday new riders). A negligible number of new riders stated that service changes were the primary reason for their change to transit, with the percentage so responding on weekdays, Saturday, and Sunday below the indicated reliability of the survey. Remaining new riders selected "other" as the reason for their change to transit. Volumes obtained for each response for weekday new riders are given in Table 2. Volumes for all riders on weekend days are given in Table 3.

In structuring the survey questionnaire, it was implicitly assumed that either fare or service would be the reason for change of mode. The large proportion of responses selecting neither of these two reasons strongly indicates that there is not a simple dichotomy but that there is severe overlapping of fare and service considerations in the decision to change one's mode to transit. The relative weights of these two factors in the complex mode choice decision, however, are not available from this research.

Although there is no basic reason for rejecting the results of this survey regarding reason for change to transit, the initial inference that might be drawn is contrary to previous research and in part also to intuitive reasoning. The magnitude of the response in the "other" category clearly indicates that no definitive conclusion can be drawn from this study. There is clear indication of the importance of fare, but the importance of service improvements cannot be minimized strictly from the apparently low proportion shown in the survey. It is probable that service considerations are present in the decision categorized as "other" in the responses, and it is also likely that the proportion attributed to fare may be somewhat overstated due to publicity factors. However, even with these constraints, it is clear that reduction in fare is one method by which transit ridership may be increased. Service changes are individually of small impact, whereas fare reduction is newsworthy and has a large impact on public awareness of transit.

It cannot be concluded that service improvements are of small significance in increasing transit ridership. It can be concluded, however, that in Atlanta, as a result of increased public awareness of reduced fares, and only limited implementation of major service improvements at the time of the survey, fare was the primary single reason for increased ridership.

Diversion

The second question was How much automobile traffic has been diverted to transit?

On the weekday 41.8 percent of new riders, some 21,642, previously made the trip now made on transit by driving an automobile. An additional 21.9 percent of weekday new riders, some 11,324, previously made the trip now made on transit by riding in an automobile driven by someone else. In total, almost two-thirds (63.7 percent or 32,966) of the new riders each weekday made the trip now made by transit in an automobile either as a driver or as a passenger. A total of 21,642 automobiles have been removed from the streets, either entirely or at least for the primary portion of the trip during the weekday. The breakdown by time period within the day is given in Table 4.

From Table 4 it can be seen that the largest volume of automobiles diverted occurs during the afternoon peak period from 3 to 6 p.m. If it is assumed that 50 percent of this volume, or 3,753, occurs during the highest volume 1-hour period, then to achieve stable flow conditions for this number of vehicles on a single highway facility would require a 4- to 6-lane freeway, according to the requirements published in the Highway Capacity Manual.

An additional point of interest is that 21.5 percent of the weekday new rider (11,151) trips were not made before the rider made the trip on transit.

On the weekend almost one-third of the new riders previously made the trip by driving an automobile, with a total of half of the new riders previously making the trip either

Table 1. Composition of increase in ridership.

Time	Category	Number	Percent	Percent Added
Weekday	Continuing old riders	185,091	100	
	Induced old riders	—	—	
	New riders	51,788	28.0	
	Total	236,879	128.0	
Saturday	Continuing old riders	81,440	100	
	Induced old riders	15,954	19.6	(47.8)
	New riders	17,452	21.4	(52.2)
	Total	114,846	141.0	(100.0)
Sunday	Continuing old riders	24,062	100	
	Induced old riders	12,032	50.0	(63.5)
	New riders	6,923	28.8	(36.5)
	Total	43,017	178.8	(100.0)
Seven-day week	Continuing old riders	1,030,957	100	
	Induced old riders	27,986	2.7	(9.0)
	New riders	283,315	27.5	(91.0)
	Total	1,342,258	130.2	(100.0)

Table 2. Stated reason for change to transit: New riders, weekday.

Reason	Number	Percent
Fare only	29,145	56.2
Service only	1,487	2.9
Other	21,156	40.9
Total	51,788	100.0

Table 3. Stated reason for change to or increased use of transit: New riders and all riders, weekend.

	New Riders		All Riders	
Reason	Number	Percent	Number	Percent
Saturday				
Fare only	8,607	49.3	40,069	34.9
Service only	503	2.9	2,842	2.5
Other	8,342	47.8	71,935	62.6
Total	17,452	100.0	114,846	100.0
Sunday				
Fare only	3,675	53.1	15,083	35.1
Service only	209	3.0	589	1.4
Other	3,039	43.9	27,340	63.5
Total	6,923	100.0	43,012	100.0

Table 4. Weekday distribution of previous automobile drivers.

Time Period	Number	Percent
6-9 a.m.	4,990	23.0
9 a.m.-3 p.m.	5,582	25.8
3-6 p.m.	7,506	34.7
Remainder of day	3,564	16.5
Total	21,642	100.0

Table 5. Previous travel mode for new riders.

	Weekday		Saturday		Sunday	
Mode	Number	Percent	Number	Percent	Number	Percent
Auto driver	21,642	41.8	5,800	33.2	2,057	29.7
Auto passenger	11,324	21.9	3,274	18.8	1,477	21.3
Walk	2,328	4.5	1,348	7.7	1,076	15.5
Other vehicle	5,343	10.3	1,938	11.1	440	6.4
No trip	11,151	21.5	5,092	29.2	1,873	27.1
Total	51,788	100.0	17,452	100.0	6,923	100.0

as driver or as passenger. Also, approximately one-fourth of weekend new riders are making trips that they did not make before the MARTA program was initiated. The actual volumes and percentages for weekday and weekend previous travel mode are given in Table 5.

Rider Characteristics

The third type of questions concerned What are the characteristics of transit ridership now as compared to before MARTA? What are the differences between the old and new riders?

If the November 1972 survey is compared with the October 1970 survey, it may be seen that total weekday ridership is up 17 percent, from 201,734 passengers per day to 236,879. It should be noted that between October 1970 and the initiation of the MARTA program the historically observed decline of approximately 5 percent per year in ridership had been continuing in Atlanta. Therefore the increase between October 1970 and November 1972 of 17 percent is consistent with the overall increase determined in this study of 30.2 percent. Within the total weekday ridership, weekday revenue passengers are up 25 percent, from 151,767 to 189,969.

Between October 1970 and November 1972 the percentage of non-home-based trips, those trips with neither end at home, increased from 5.9 percent to 14.0 percent, showing greater mobility during midday and evening. The percentage of non-work trips, coincident with the previous observation, increased from 29.9 percent to 39.9 percent. The percentage of park-and-ride, where a patron drives to a transit stop and leaves the car all day, increased from 2.8 percent to 4.8 percent. This is a small number, but it should be remembered that at the time of this survey no formal park-and-ride facilities had been established by the Authority. The percentage of kiss-and-ride trips, where the transit rider is driven to the stop and picked up at the end of the day, increased from 4.2 percent to 14.4 percent, also small in number but indicative of a significant change in ridership patterns.

Data from the November 1972 survey show that on the weekday nearly two-thirds (64.3 percent) of new riders are between 18 and 35, compared to only half (48.2 percent) of old riders. With increasing age, the proportion of new riders as a part of the total transit rider population decreases, emphasizing the conclusion that transit has been made attractive to a different segment of the population. In comparison, 1970 population figures for Fulton and DeKalb Counties combined show 25.7 percent of the total population to be between the ages of 18 and 34 and 38.3 percent to be 35 and older. Where old riders generally follow the area-wide population age distribution, new riders show a larger attraction to a smaller percentage of the total population.

New riders are almost equally divided between male and female (51.1 percent female, 48.9 percent male). This is very close to the 1970 population figures for Fulton and DeKalb Counties, which show males to constitute 47.7 percent of the total population and females 52.3 percent. In contrast, for old riders the proportional part of female riders is twice that of males (64.9 percent female, 35.1 percent male). The distribution of new riders is nearly that of the total population, also indicating a stronger attraction to a different segment of the total population.

Of new riders, 60.8 percent are black and 39.2 percent are white, compared with old riders who are 72.1 percent black and 27.9 percent white. Of all riders, 70.4 percent are black and 29.6 are white. This is the reverse of the racial distribution for Fulton and DeKalb Counties as indicated in 1970, where 71 percent are shown as Caucasian and 29 percent are shown as Negro and other. Although new riders do show a larger proportion of white riders in comparison to old riders, the total is still not representative of the entire service area population.

Of those who reported their family income level (84.8 percent of new riders and 82.8 percent of old riders), 30.4 percent of new riders have family incomes over $10,000 compared to only 21.2 percent of old riders. The 1970 census figures show 53.6 percent of families within the two counties having incomes over $10,000. While transit has been made more attractive to higher income riders, the income distribution of old and new riders is still far from representative of the income distribution of the entire service area.

More than half (55.7 percent) of new riders reported that no automobile was available for their trip either as driver or passenger, compared to nearly three-fourths (72.3 percent) of old riders. Only one-fourth (27.7 percent) of new riders have no family automobile, compared to nearly half (45.5 percent) of old riders. It is interesting to note that the 55.7 percent of new riders who indicate they are "captives" corresponds closely to the 58.2 percent of new riders that were previously auto passengers (21.9 percent), utilized some other vehicle type (10.3 percent), walked (4.5 percent), and did not previously make the trip (21.5 percent). A much larger percentage of new riders than of old riders have automobiles in their families and have automobiles available to them for their trip but have selected transit on a basis of choice.

Nearly half (48.1 percent) of new rider trips are for reasons other than to and from work, while slightly more than one-third (37.7 percent) of old rider trips are for purposes other than work. This indicates a higher mobility and freedom to make non-work trips among new riders.

Nearly three-fourths of both new (73.8 percent) and old (70.9 percent) riders walk to the bus they ride. Only 16.1 percent of new riders reached the bus they may be riding at any point in time by transferring from another bus, compared to 20.8 percent for old riders. Only 3.2 percent of new rider trips are preceded by a drive-and-park activity, compared to only 1.6 percent for old riders. Almost equal proportions of new (5.0 percent) and old (6.0 percent) riders reached their bus by riding with someone driving an automobile. While the number of drive-and-park riders is a small percentage of the total ridership, it should be noted that 4,560 vehicles are parked per day while their drivers take transit for a portion of their trip. All of this parking is done on an informal basis, with no provision of lots by the Authority.

When a transfer is required by new riders, only 5 percent of those transferring make more than one transfer, while 16 percent of old riders who transfer make more than one transfer. It is indicated that new riders do not make trips requiring transfers as often as old riders, and when transfers are required a much smaller proportion of new riders make more than one. New riders are more likely to use park-and-ride for access to transit, but new riders and old riders show almost equal propensity to ride to transit as an auto passenger. There may well be a correlation between the higher usage of park-and-ride and kiss-and-ride activity with the lower transfer rate for new riders. Obviously, with higher automobile ownership ratios the new rider has more flexiblity to drive to a transit line that provides more direct service, thereby reducing the need for transfers, whereas old riders, who do not have as high a ratio of automobile availability, are forced to usethe closest transit line regardless of thetransfer requirements.

Service Quality

The fourth question group was How does the quality of service compare now with the quality before MARTA? What do transit riders think of the quality of service? What types of improvements do the riders want? Is there a difference in the types of service improvements that are desirable to new riders and those desired by old riders?

In the opinion of the old rider, transit service has improved or remained unchanged, as evidenced by 38.3 percent of weekday old riders who think service is improved and 54.6 percent who believe service is unchanged. Only 6.9 percent of weekday old riders believe service has deteriorated. Comparable figures were reported on Saturday and Sunday (Table 6). Both new riders and old riders perceive service quality as good on weekdays, Saturdays, and Sundays, with over half of both new and old riders selecting "good" when offered a choice of "good", "fair", or "poor". On weekdays and Saturdays approximately 40 percent of new riders and old riders thought service should be classified as fair. On Sundays a smaller percentage, approximately one-third, believe service to be fair, but a larger percentage on Sunday select good than for weekdays and Saturdays. Overall, in excess of 90 percent of new riders and old riders believe service to be good or fair, with the exception of old riders on Sunday, when 5.0 percent had no opinion. The actual responses are given in Table 7.

Both new and old riders agree on five most important service improvements, on weekday and weekend. These five improvements are the first choice of three-fourths of all riders on weekdays, Saturday, and Sunday. These five selections are increased

Table 6. Change in quality of service: Old riders, weekday and weekend.

	Weekday		Saturday		Sunday	
Quality	Number	Percent	Number	Percent	Number	Percent
Improved	101,075	54.6	49,653	51.0	16,052	44.4
Unchanged	70,876	38.3	41,271	42.4	15,545	43.1
Deteriorated	12,831	6.9	5,577	5.7	4,109	11.4
No opinion	309	0.2	893	0.9	388	1.1
Total	185,091	100.0	97,394	100.0	36,094	100.0

Table 7. Perceived quality of service: New and old riders, weekday and weekend.

	Weekday		Saturday		Sunday	
Quality	Number	Percent	Number	Percent	Number	Percent
New riders						
Good	28,694	55.4	8,870	50.8	4,445	64.2
Fair	20,464	39.5	7,159	41.0	2,035	29.4
Poor	2,630	5.1	1,423	8.2	443	6.4
No opinion	–	–	–	–	–	–
Total	51,788	100.0	17,452	100.0	6,923	100.0
Old riders						
Good	103,887	56.1	53,773	55.3	20,733	57.4
Fair	67,109	36.3	37,241	38.2	11,729	32.5
Poor	13,200	7.1	5,568	5.7	1,835	5.1
No opinion	895	0.5	812	0.8	1,797	5.0
Total	185,091	100.0	97,394	100.0	36,094	100.0

Table 8. Improvement priorities indicated by all riders on weekday, Saturday, and Sunday.

Type of Improvement	Weekday (percent)	Saturday (percent)	Sunday (percent)
Increased frequency of service	22.0	19.4	18.7
Improved schedule reliability	17.1	15.2	15.0
Waiting shelter	15.7	17.0	16.7
Increased seat availability	13.2	12.5	9.3
Increased weekend service	7.8	10.8	16.8
Subtotal top five	75.8	74.9	76.5
Improved schedule information	6.8	7.5	6.0
Improved transfer efficiency	4.2	5.5	4.2
Air-conditioned buses	4.4	4.1	3.0
Improved operator attitude	2.6	3.4	3.6
Park-and-ride lots	1.6	0.8	0.9
Subtotal next five	19.6	21.3	17.7
Increased late-in-day service	0.5	0.5	0.3
Other/no opinion	4.1	3.3	5.5

Table 9. Financial effects of increasing ridership through reducing fares.

Condition	Revenue Trips	Revenue ($)	Percent Change in Revenue Trips	Percent Change in Revenue	Average Cost per Revenue Trip Generated[a]
Basic condition at 40-cent fare	825,000	330,000	–	–	–
Fare decreased to 25 cents	1,007,800	251,950	+22.2	-23.7	0.427
Fare decreased to 15 cents	1,051,700	157,750	+27.5	-52.2	0.760

Average marginal cost per revenue passenger gained through additional fare reduction from 25 cents to 15 cents = $2.146

[a]Cost in terms of foregone revenue.

frequency, improved schedule reliability, bus shelters, seat availability, and improved weekend service. It should be noted, in line with previous analysis indicating that a negligible percentage of new riders and old riders are riding because of service changes, that four of the five types of service improvements selected by new and old riders as being the most important are the types of improvements that have been made and that people have recognized as resulting in improved or at least maintained service. This indicates the validity of the explanation given previously that the types of service change made are not usually recognizable by the transit user specifically as improvements and that the improvements that were made are not dramatic enough to capture the attention of the rider. The actual volumes of all riders selecting each of the service improvements as their first choice are given in Table 8.

Fare Elasticity

The fifth question asked was Did the fare need to be reduced as much as it was in order to achieve significant increases in transit ridership?

Included in the questionnaire for new rider interviews was the query, Would you have made this trip by bus today if the fare were 25 cents, or if it were 40 cents? On a 7-day week basis there are 283,315 new transit riders riding at the 15-cent fare, which is an increase of 27.5 percent over the 7-day volume of continuing old rider trips of 1,030,957. In response to the question to determine if they would be riding if the fare were 25 cents, the 7-day week volume of new riders at 25 cents is indicated to be 228,559, which is 80.7 percent of the total new rider trips under the 15-cent fare. Interestingly enough, 131,261 of the weekly new riders indicated they would continue to ride if the fare were raised to the original 40-cent level. This number is 46.3 percent of the total weekly new riders, very close in magnitude to the number of new riders who stated the primary reason for their change to transit was other than fare.

From survey results it is clearly indicated that, had the objective of fare reduction been to increase ridership rather than to achieve equity in the method of funding, then a smaller reduction would have achieved a substantial increase in ridership. However, even with a lesser reduction in fare, the increase in ridership would not have been sufficient to compensate for revenues foregone through the fare reduction. In Table 9 it is indicated that, in terms of estimated weekly revenue trips, a decrease in fare to 25 cents would have resulted in an increase in revenue patronage, but with a decrease in fare revenue of 23.7 percent. However, it is indicated that the decrease in fare to 15 cents resulted in a decrease in fare revenue of 52.2 percent.

In terms of foregone revenue, and therefore under Authority funding a public cost, and discounting transfer trips as well as all benefits accrued such as increased mobility, weekly automobile trips diverted to transit are estimated on the order of 116,000, at a cost of $172,250. The cost per auto trip diverted is therefore $1.48, or, assuming an average trip length of 10 miles, 14.8 cents per vehicle-mile of automobile travel diverted to transit.

GENERAL SUMMARY

1. The indicated increase in ridership for the 12 months ending June 30, 1973, was 30.2 percent, of which 91 percent is due to trips made by new riders and only 9 percent is due to increased tripmaking by old riders. It is also indicated that the fare reduction, taken alone, is more significant in attracting new riders to transit than are service changes taken alone. However, there is a large proportion of new riders who are attracted by other, undetermined factors and/or a combination of fare reduction and service change.

2. Almost two-thirds (63.7 percent or 32,966) of weekday new transit riders previously made the trip now made by transit in an automobile either as the driver or as a passenger. Nearly half (41.8 percent or 21,642) of weekday new riders previously made the trip now made by transit by driving an automobile. Increased mobility is evidenced by the 26.0 percent (13,379) of new riders who previously walked or did not make the trip at all. Over 20,000 automobile trips have been removed from the streets entirely or at least for the major part of the trip, 58 percent of this during the peak-volume periods.

3. New riders are generally younger and wealthier than the old riders, with a higher proportion of males and whites. The new riders tend to ride later during weekdays and not as much on weekends. A larger proportion of new riders have an automobile available but choose to ride transit, primarily because of the low fare. The new riders show a higher propensity to make trips other than home-to-work by transit. The amount of park-and-ride and kiss-and-ride access to transit service has more than doubled, even though MARTA has not as yet implemented specific action encouraging this activity.

4. Old riders believe that transit service has improved or remained unchanged, generally. New and old riders alike on weekdays and weekends believe that increased frequency, improved schedule reliability, bus shelters, improved seat availability, and improved weekend service are the most important types of improvements that can be made. It is also apparent that slight improvements in transit services are not significant enough to be noticed by the transit rider even though accumulated small improvements—in headways, for example—may account for significant increases in total transit operations.

5. A lesser decrease in fare, to 25 cents, would have achieved approximately 80 percent of the increase in ridership that was realized with the decrease in fares to 15 cents. Had the objective of fare reduction been to increase ridership, then the amount of decrease need not have been as large in order to achieve significant increases in ridership. However, even with the smaller reduction, an operating deficit would have resulted.

ACKNOWLEDGMENTS

This paper is based on the report, "The Effect of Fare Reduction on Transit Ridership in the Atlanta Region—Summary Report No. 1, Analysis of Transit Passenger Data", prepared by the Metropolitan Atlanta Rapid Transit Authority. The research effort was funded in part by the U.S. Department of Transportation's Urban Mass Transportation Administration through the Atlanta Regional Transportation Program, conducted by the Metropolitan Atlanta Rapid Transit Authority, the Atlanta Regional Commission, and the Georgia Department of Transportation.

REDUCING THE TRAVEL REQUIREMENTS OF THE AMERICAN CITY: AN INVESTIGATION OF ALTERNATIVE URBAN SPATIAL STRUCTURES

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Little attention has been given to investigating the potential for gradually restructuring the city to reduce its built-in requirements for transportation. This paper investigates this potential by analyzing the transportation requirements of some alternative urban spatial structures. A computer-directed search procedure is developed and tested by using two simple urban structures. These experiments form the basis for an investigation of a larger urban structure based on the 1970 urban pattern of western King County, Washington. The results of these investigations indicate that, by moving about a third to a half of the people and about a third of the jobs to other locations, substantial reductions (50 percent or more) in travel requirements could be obtained while also improving overall access levels. Although structural changes of this magnitude are not feasible in the near term, many cities may be growing by this much in the next 20 to 30 years. The potential of nontransportation solutions to transportation problems appears to be a significant but neglected area for policy-oriented research investigations.

•THE need to reduce the transportation requirements of the American city is becoming more urgent. Part of the impetus behind this need comes from a growing realization that we must find many ways to conserve energy in the future. Other problems such as poor air quality and the citizen revolt against urban freeways have also had an important role in stimulating renewed interest in searching for ways to reduce the need for transportation in cities. Proposed solutions to these problems often take the form of plans to build new transit facilities such as rail mass transit or automated personalized rapid transit. To date, little attention has been given to investigating the potential of gradually restructuring the city so as to reduce its built-in requirements for transportation. Few people have asked, "Can significant reductions in the transportation requirements of a city be achieved by changing its urban spatial structure in certain ways?" It is the purpose of this paper to investigate this question by analyzing the transportation requirements of some alternative urban spatial structures. The approach used is experimental in nature and involves the use of a computer-directed search for urban spatial structures that have minimal transportation requirements. The effort here is to deal with what we perceive to be the basic causes of the urban transportation requirements instead of examining only the symptoms of these problems.

Another way of conceptualizing the approach is to ask, "For a given transportation system, how much could travel be reduced by shifting or rearranging the location of people and jobs?" If, for example, we could show that by shifting the location of 10 percent of the people and jobs in a city, one could expect to see total journey-to-work travel in that city decline by 15 percent, it would seem logical to closely examine ways

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

in which such a restructuring of the city might actually be accomplished. Few of the recent and very expensive proposals to construct transit facilities in major cities can demonstrate that they will reduce the travel requirements of the population they will serve. Almost all of them will allow and encourage more people to travel more. While this may be viewed as being "good" in terms of helping to satisfy our virtually insatiable desire for more and more individual mobility, it is inconsistent with our important needs to conserve energy, improve air quality, and minimize disruption to existing parts of the urban fabric. At some point in our history, we will have to face up to the question, "How much individual mobility is enough?" There are important trade-offs between mobility and the various aspects of environmental quality that are only dimly perceived by most people at this time. Our view is that, in general, more mobility means less environmental quality, unless very large sums of money are invested for environmental protection in the transportation arena. If this is true and if environmental quality is getting to be as highly valued as mobility, then it makes sense to think much harder about ways to preserve and enhance the environmental quality of our cities. If we can refrain from building new and expensive transportation facilities while preserving current mobility levels in the future, we can expect to free the resources needed to make our cities much more livable than they are now. Our quest, then, is to search for nontransportation solutions to the urban transportation problem where such solutions can be expected to (a) result in equal or better individual mobility and (b) produce a better level of environmental quality in the city. A nontransportation solution is one that involves no new transportation facility or service but instead involves a rearrangement of a particular urban spatial structure such that some part of the present transportation requirement of the city is reduced significantly.

Some additional background and perspective for this rather radical approach to the urban transportation problem are presented later in this paper. An automated search procedure designed to "discover" high-performance (i.e., low-travel-demand) urban spatial structures is presented and is then applied to two simple networks to test its utility. Then the search procedure is applied to an abstraction of the urban form of the western part of King County, Washington, an area which included more than 1 million people in 1970. Finally, some conclusions from this study and some suggestions for further research are given.

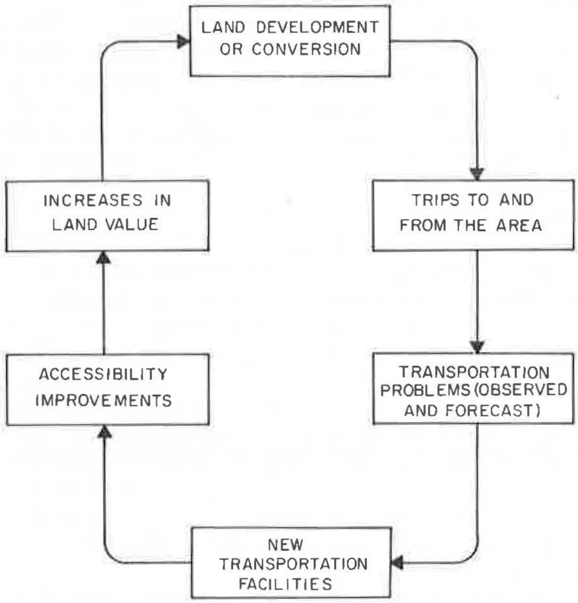
A PERSPECTIVE ON THE LAND USE-TRANSPORTATION RELATIONSHIP

The relationship between land use and transportation can be conceptualized as a circular chain as shown in Figure 1. Within this circular chain, land development determines the pattern of trips in the urban area simply because the land use pattern represents the locations of all trip origins and destinations. These trips, when aggregated into an urban travel pattern, define the transportation requirements for an area. As problems arise (or are forecast to arise), additional transportation facilities are constructed, providing increased accessibility to certain parts of the area. This new accessibility causes changes in the value of the parcels of land served by the new facilities. The land is then put to more intense uses, and the circular chain of relationships continues until no further development of the land is possible.

The nature of this circular chain raises some questions about the decision-making process that has traditionally been used to plan transportation facilities. Specifically, if new facilities are built to serve only those needs determined by present trip patterns and projections of present patterns, then it is clear that the land use implications of such decisions are not being given sufficient consideration. All too often, this emphasis on one part of the circular relationship results in a serious lack of attention to the remaining interacting elements.

Even if the circular nature of the relationship between transportation and land use in urban areas becomes widely recognized, another question arises concerning the extent to which this knowledge will be used to guide the future development of the area. Some type of answer to this question should be formulated by the people in each metropolitan area. While this has been rarely done in the past, at least one metropolitan

Figure 1. Circular relationship between land use and transportation activities.



area (Minneapolis-St. Paul) has recently made the decision that capital investments in transportation facilities will be used as a tool to guide development as well as to serve it (2).

At the national level, the National Academy of Engineering has recently completed a study for the U.S. Department of Transportation that recommends areas for future research and development in the field of urban transportation (6). One area recommended for study was the effect of city design on urban transportation:

> The increasing focus on the quality of urban life clearly calls for a better understanding of the interactions and relationships between urban transportation systems and the functions of metropolitan areas. This, in turn, requires an enhanced program of analysis and real world experimentation. . . .Satisfactory urban transportation solutions depend to an important degree on the origin and arrangement of the city, on the creation of an attractive environment, and on a desirable growth policy. More satisfying urban communities depend to an important degree on the design of transportation systems, including the effective use of transportation infrastructure as an aid to good urban design and environment.

Because there is a possibility that more and more metropolitan areas will seek to use transportation investments as tools to guide their development in the future, some further investigation into the land use-transportation relationship is urgently needed. These investigations should make use of methods that adequately represent the circular nature of that relationship, and they should be capable of answering at least three questions:

1. What are the transportation criteria with which we can evaluate alternative land use patterns?
2. How can we use these criteria to discover those land use patterns that are most desirable?
3. After desirable patterns of land use have been identified, how can we determine which transportation policies can best assist the achievement of such patterns?

The first question is not intended to suggest that only transportation criteria should be used to determine favorable urban development patterns. Any choice of this type must depend on a combination of criteria and goals covering all the varied activities in the urban area. However, it will certainly be helpful to identify those transportation criteria that are important and to discover those land use configurations that exhibit the best performance based on the chosen criteria.

Further, other factors that influence land use in a manner similar to transportation may also be used to guide urban development toward desirable patterns, once those patterns are identified. Therefore any procedure that can answer the first question posed above will have application to capital-investment programs for utility planning (such as power, water, and sewage systems) and open-space planning as well as transportation-system planning.

Providing the answers to the second question will require the development of automated search procedures designed to discover high-performance land use patterns that best satisfy the criteria used. The next section of this paper describes our initial effort to develop such a procedure.

Providing the answers to the third question will require development of a model designed to simulate all of the interrelated elements shown in Figure 1. This model must include a feedback structure that will allow the simulation of the effects of alternative transportation and land use policies, so that one can identify policies that will move the metropolitan area toward a spatial structure that has been identified as most desirable. This task is well beyond the scope of this paper.

Basic to an understanding of any approach to the problem of identifying an optimal urban form is the concept of a combinatorial space. This term simply represents the set of all the possible urban configurations for any particular geographic setting. For example, if we were dealing with a situation where there were 100 different feasible and logical ways to distribute people in an urban area, 50 different ways to distribute jobs, and 5 different ways to design the transportation network, we would have to deal with 25,000 alternative urban situations ($100 \times 50 \times 5 = 25,000$). In most practical situations, the number of urban structure combinations that arise (even when the urban area is characterized in very abstract terms) is astronomical in size. One cannot hope to be able to examine all of these alternatives in any practical situation of this type. One must either eliminate most of the alternatives by (a) making a series of judgments, or (b) use a computer to search for a satisfactory solution within this set of all possible combinations (i.e., the combinatorial space), or (c) use some type of analytical procedure such as combinatorial programming to find a solution with the desired performance level (8). We wish to do something better than relying totally on intuitive judgment but have found our problem to be unsuited to the more elegant combinatorial programming approach. Thus, our attention has been directed to the development of ways to use the computer to search the combinatorial space formed by alternative urban configurations.

Five previous studies of this topic have influenced our approach to this problem. Hemmens (5) investigated the transportation requirements of a simplified urban form consisting of 37 zones arranged in a grid pattern. Thirty alternative urban structures were studied where residential, commercial, and other employment land uses were located in various locational patterns. Hemmens used a linear programming algorithm to assign home-to-work and home-to-shopping trips to shortest path routes. The programming model does not attempt to simulate the behavior of tripmakers, but rather makes assignments such that for each configuration the total travel, in man-minutes, is a minimum. The only criterion used to judge the desirability of one spatial structure over another was the aggregate time required to complete all the work and shopping trips in the city.

The 30 selected configurations evaluated by Hemmens included various location patterns for the two named land uses and also included variations in the transportation system connecting the zones. However, several restrictions were placed on the configurations that severely limited the number of possible cases. The 30 cases studied represent only a small fraction of the total possible cases, a number that is astronomical in size. The land use-transportation combinations that were chosen for examination were selected on an intuitive basis and may or may not represent the most significant subset of combinations. Hemmens did not find much variation in performance (i.e., total travel) among the alternatives he examined, and this may be the result of a scope that was too restrictive.

Harris (4) mentions the application of combinatorial methods to the regional planning process and discusses two reasons why such an application would be difficult. One application is the evaluation of alternative transportation system plans. Harris suggests that it might be possible to cast the set of all possible alternative transportation systems as a combinatorial space and evaluate all of them by means of high-speed digital computers, retaining only a few of the best combinations for output. Another suggested application is that of finding the best sequence of development for a particular urban region. This sequencing problem could be defined as a combinatorial space representing all possible development sequences, and then the set of sequences could be evaluated automatically, using a set of cost or other criteria representing a time dimension to the combinatorial space.

The disadvantages of this approach cited by Harris are

1. The space containing all possible combinations for any realistic problem is so large that the evaluation of all combinations would be prohibitively expensive and time-consuming.

2. The combinatorial space could not be expected to be smooth or continuous, and any search procedure that attempts to find "best" combinations on the basis of gradients would likely be ineffective due to the problems of local optimums.

This study is designed primarily to examine the second of these assertions within an experimental framework.

A recent study of the Detroit metropolitan area by Doxiadis (1) tends to confirm at least the first difficulty mentioned by Harris. The Detroit study used a combinatorial approach and quickly identified about 49,000,000 alternative future development patterns for the area. Most of these alternatives were eliminated by using intuitive judgment, and only about 40 were examined in detail by the study staff. This study required 5 years and cost approximately 3 million dollars, but in fact only a very small proportion of all of the possible alternatives were closely examined. The selection of the set for detailed study was based largely on human judgment and was not the result of any automated search or evaluation of the full set of alternatives.

A characteristic common to both the Hemmens and Doxiadis studies is that, while the combinatorial concept was used to establish a framework for the study, the actual set of combinations selected for detailed study was defined using only a series of human judgments. Each such judgment has the effect of eliminating thousands or tens of thousands of alternatives. In such situations, one is never quite sure what good alternatives might be lost in this type of elimination process.

In an effort to overcome the difficulties presented by a very large combinatorial space while at the same time making use of human judgment, Goldman (3) developed an interactive graphic computer program in which the human analyst chooses an urban configuration and submits the configuration to the computer for analysis. The results of the automated analysis are then presented to the analyst in the form of a series of graphic displays. The analyst then makes judgments based on these displays, modifies the configuration, and resubmits the modified configuration to the computer for analysis. Because the cycle of modification and evaluation can be performed very quickly, the analyst can construct and evaluate several alternatives quickly and can usually derive a series of successive configurations, each of which has a higher level of performance.

However, it has been pointed out by Rapp (7) that, in any situation in which the human analyst must deal with a very large combinatorial space, it may be very difficult to decide how to modify the present configuration in order to move it toward the established performance objectives. That is, the analyst will, more often than not, be overwhelmed by the large number of possible choices. In such cases, he will either give up or make a series of guesses which, more often than not, will not lead to the discovery of a satisfactory solution.

A possible solution to this problem is the automation of the process of modifying configurations in addition to the analysis of each chosen configuration. With the combinational framework established (i.e., when each possible configuration can be defined by a specific combination of the variables used), the choice of a modified configuration (i.e., the next configuration) for analysis requires only that the choice be based on some numerical measure of performance. In this way, the process of modification and evaluation can be completely automated. Human judgment is needed only to determine (a) the original specification of objectives, in numerical terms, as derived from the desired level of performance of the configuration and (b) the starting configuration or position where the search is to begin. A completely automated search process makes maximum use of the speed available in digital computers to search large combinatorial spaces. The results of this search will be the most desirable configurations that can then be subjected to further examination. In contrast to the approaches of both Hemmens and Doxiadis, an automated search process does not require one to intuitively select various configurations for further detailed study. Rather, it finds or discovers a set of configurations that satisfy the given objectives without any further input from the human analyst.

This paper examines the concept of automated search algorithms that operate within combinatorial spaces as useful tools in examining the transportation requirements of alternative urban structures. Our purpose is to identify those urban structures that are most satisfactory according to the transportation criteria selected.

Procedures will be presented that allow various possible urban structures to be represented as points in a combinatorial space. A method is adopted for evaluating each candidate configuration according to a set of transportation criteria chosen by the user. A prototype search algorithm will be presented and evaluated by application to two simple and small combinatorial spaces representing hypothetical urban situations. The performance of the algorithm in these test cases is discussed and provides a basis for the investigation of a large problem representing an actual urban configuration.

The criteria for desirable urban structures used in this paper are based exclusively on the internal transportation requirements of each structure, and therefore no claim is made that the structures identified are desirable in any other sense.

DEVELOPMENT OF THE AUTOMATED SEARCH ALGORITHM

This section presents a concise statement, in mathematical terms, of the problem of finding desirable urban structures (cast in combinatorial form) and gives a description of the search algorithm used for this purpose.

Problem Statement

The problem to be examined here is that of arranging a specified number of people and jobs on a fixed transportation network (a set of nodes, links, and travel times) that represents the transportation facilities available in an urban area. Measures of a societal utility of alternative arrangements of people and jobs will be based on the internal travel requirements of each arrangement. The search algorithm then is to find an arrangement that satisfies the objectives specified.

Each arrangement or configuration of people and jobs on the nodes of the network is defined by a set of configuration variables

$$X = [x_1 \ldots x_n] \qquad (1)$$

These variables are the number of people (tripmakers) and the number of jobs at each node in the network. Since we consider only journey-to-work travel, these variables correspond to the spatial distribution of residences and work places on the network.

Constraints are specified that provide upper and lower limits for the number of people and jobs at each location (node) on the network. Another constraint specifies that the total number of trips made is a constant, since the objective is to find a more desirable arrangement for a constant number of trips. Each possible arrangement of people and jobs constitutes one configuration, and any configuration that does not violate any constraint is called a feasible configuration.

The second set of variables is called the impact set:

$$T = [t_1 \ldots t_m] \tag{2}$$

For our problem, the impact variables are the link flows and accessibilities generated by the configuration of people and jobs on the network.

A set of constants is specified that defines the network of locations (nodes) and their connecting links:

$$C = [c_1 \ldots c_p] \tag{3}$$

The constants describe the physical layout of the network and the travel times over each link of the network in the urban area.

The impact variables are related to the configuration variables and constants by the system equations:

$$\begin{aligned} t_1 &= g_1(x_1 \ldots x_n,\ c_1 \ldots c_p) \\ &\vdots \\ t_m &= g_m(x_1 \ldots x_n,\ c_1 \ldots c_p) \end{aligned} \tag{4}$$

A gravity model is used as a basis for these system equations in this study.

The relative desirability of each configuration is determined by a set of performance measures:

$$\begin{aligned} PM_1 &= h_1(t_1 \ldots t_m) \\ &\vdots \\ PM_r &= h_r(t_1 \ldots t_m) \end{aligned} \tag{5}$$

These measures are derived from the impact variables; that is, they are functions of the accessibilities and patterns of trips generated by any particular configuration of people and jobs on the network.

Performance Measures

Performance measures are one way of summarizing the characteristics of each configuration. These characteristics must be summarized and expressed numerically because they form the basis for the decision rules used by the search algorithm. The performance measures used in this study are discussed in the following.

Total Travel—Total travel is the sum of all travel, measured in person-minutes, required to complete the set of all work trips from all the origins to all the destinations in the network. It is not only a measure of the collective time required to satisfy all trip demands, but it is also an indicator of the magnitude of secondary effects associated with travel such as the consumption of energy and the level of exhaust emissions from vehicles:

$$PM_1 = \sum T_{ij} t_{ij} \tag{6}$$

where

PM_1 = total travel;
T_{ij} = number of trips between origin i and destination j; and
t_{ij} = time required to travel from origin i to destination j by the shortest path.

The search algorithm will seek those configurations that require the least total travel to satisfy their trip requirements (i.e., moving everyone from their home to their job).

Total Weighted Accessibility—Total weighted accessibility is a measure of aggregate nearness of each residential location to all employment locations in the urban area:

$$PM_2 = \sum_i P_i \sum_j \frac{A_j}{t_{ij}^b} \qquad (7)$$

where

PM_2 = total weighted accessibility;
P_i = trips produced at origin i (residential location);
A_j = trips attracted to destination j (job location);
t_{ij} = time required to travel from origin i to destination j by the shortest path; and
b = exponent reflecting the friction of space or average difficulty of overcoming spatial separation in an urban area.

The value of the travel time exponent used in this measure is 2.0, an average of those values commonly used in urban transportation studies. Total weighted accessibility is not a measure of travel but rather a measure of overall spatial relationship between home and work locations in the urban area. Configurations that have a higher total weighted accessibility are interpreted as having more social utility than those that have lesser weighted accessibilities.

Average Link Load—Average link load is an indication of the average level of use (i.e., average loading) of the transportation network. Because only internodal trips load the links, average link load relates only to internodal travel, as distinguished from the intranodal trips, which both originate and end within a single location (zone):

$$PM_3 = \frac{\sum_k LO_k}{NL} \qquad (8)$$

where

PM_3 = average link load;
LO_k = number of trips on link k; and
NL = total number of links in the network.

Maximum Link Load—Maximum link load is the largest of the loads on any link in the network:

$$PM_4 = \underset{k}{\text{Max}} \, [LO_k] \qquad (9)$$

where LO_k = number of trips on link k. Since all links are defined to be one-way links, the maximum link load is also associated with a direction. Maximum link load is a function of the concentration of internodal trips on a single link. This concentration may be considered undesirable under some conditions but may be desirable under some other conditions (e.g., the user may wish to find a configuration with a highly concentrated travel pattern in order to make best use of a high-capacity fixed-route transportation technology). However, since one of our objectives is to find urban configurations that do not require high-capacity transportation facilities, we will interpret high maximum link loads as being undesirable.

All of these measures are derived from an "all or nothing" assignment procedure. This means that all trips are assumed to use the shortest time path between each origin-destination pair of nodes. This procedure is a crude approximation to the behavior of actual tripmakers but is assumed to be sufficiently realistic for the purposes of this study.

Objective Function

In order to assess the overall utility of any particular configuration, some method is needed to combine all the performance measures into a single numerical score. However, because we wish to examine the performance of the search algorithm itself, we will use individual performance measures in separate searches and will not compute and use an overall score. This approach will permit evaluation of the search algorithm with respect to the individual performance measures and will also identify the configurations that are optimal for each performance measure. This simpler approach is viewed as a necessary step in the development of a search algorithm that can deal with multiple objectives simultaneously.

System Equations: Gravity Model

This paper used the gravity model approach described by Goldman (3) rather than the linear programming method of Hemmens (5). The gravity model is used because it better represents the behavior of actual tripmakers, as opposed to the linear programming method, which does not distribute trips in a realistic manner.

The gravity model equation is shown by Eq. 10. According to the gravity model concept, travel generated by persons in one location and jobs in another location is directly proportional to the number of persons and the number of jobs in both locations and inversely proportional to some power of the time or distance between the two locations:

$$T_{ij} = \frac{\dfrac{P_i A_j}{t_{ij}^b}}{\sum\limits_j \dfrac{A_j}{t_{ij}^b}} \tag{10}$$

where

T_{ij} = number of trips from origin i to destination j;
P_i = trips produced at origin i (residential location);
A_j = trips attracted to destination j (job location);
t_{ij} = time distance from node i to node j by the shortest path; and
b = exponent expressing the friction of travel.

The search algorithm does not necessarily require that the gravity model be used as the basis for trip distribution. Any other trip distribution technique could be substituted for it without changing the search procedure.

Specification of the Search Algorithm

The purpose of the search algorithm is to generate successively more desirable urban configurations of people and jobs as determined by the performance measures described earlier. The search algorithm is based on the concept that any distribution of people and jobs over the network of nodes can be represented as a combination of variables. Any such combination may be thought of as a point in a combinatorial space. The function of the search algorithm is to locate successively better combinations by moving about within the combinatorial space.

A flow diagram of our search algorithm is shown in Figure 2. Beginning with a starting configuration, the algorithm generates a new configuration by moving a specified number of people from the first node to the second. The travel requirements of the new configuration are calculated and compared to the values of the starting configuration. If no improvement has been found, the second configuration is eliminated and a third configuration is generated from the starting configuration by moving a block of people from the first node to the third. If this third configuration produces a score higher than the original score, it replaces the starting configuration in the memory of the computer. The process is continued until all possible node pair trip production shifts have been examined. The search is then repeated for job location shifts in an identical manner.

This is an extremely simple method of searching the combinatorial space, but it has the advantage of being very fast, and the high speed of the algorithm makes it possible to examine a vast number of configurations in a very short time.

The search algorithm can be made even faster by placing upper and lower bounds on the numbers of people and jobs located at each node. These upper and lower limits can be set by the user to restrict the search to a set of configurations considered reasonable. After each configuration is generated, it can be checked to determine if any constraints have been violated. If they have, the configuration is eliminated without being analyzed. These bounds can significantly reduce the size of the space that has to be searched.

A further increase in speed can be obtained by repeating those shifts that have generated an improved configuration. A successful shift may be repeated between the same node pair until it no longer generates a better performing configuration. In the next section we will test the performance of this algorithm in the context of two experiments.

TWO EXPERIMENTS DESIGNED TO TEST THE PERFORMANCE OF THE SEARCH ALGORITHM

The purpose here is to present a description of the two experiments that were carried out to examine the performance of the search algorithm. The results of the experiments are presented in graphic and tabular form and show both the performance of the algorithm and the characteristics of the urban patterns found by the algorithm.

Summary of Experimental Design

Two experiments were performed to evaluate the effectiveness of the search algorithm. These two experiments involved application of the search algorithm to a 3-node and a 5-node network. The combinatorial space associated with these examples was evaluated completely by examining all possible configurations before the search algorithm was applied. Thus it was possible to determine whether the algorithm was actually able to find the best configuration for each performance measure. Searches were conducted using each of the four performance measures as the objective, and several different starting configurations were used for each performance measure search as well.

Experiment I: A 3-Node Network

The first experiment consisted of an application of the search algorithm to a network of 3 nodes and 6 one-way links that formed a right triangle, as shown in Figure 3. Numbers beside the links indicate travel times along the links. These travel times are used as the measures of distance between the nodes and are represented by the symbol t_{ij} in the gravity model (Eq. 10). The distance decay exponent b in Eq. 10 has a value of 2.0 in all experiments. The intranodal time, or average time between people and jobs located at the same node, was set at 1.0.

The 3-node network is the smallest and simplest network that will yield useful information. The 3 pairs of one-way links form unequal legs of a triangle, and therefore the network is not symmetrical. The lack of symmetry means that even in this simple network one node is the most central node and one is the most remote node. In this case, node 2 is the most central and node 3 is the most remote.

The number of people and jobs to be located on this network was arbitrarily limited to a total of 300 people and 300 jobs. An upper limit of 200 people or jobs at any single node was used, and the minimum limit was set at 50. These limitations therefore allow any people-job combinations that sum to 300 people and 300 jobs, including concentrations of as many as 200 people and jobs at any node, or an even distribution of 100 people and jobs at each node.

Complete Enumeration of the 3-Node Network and Experimental Results

The process of evaluating all possible configurations within the limitations listed was carried out using a step size of 50 people or jobs. This means that each configuration differed from the previous configuration by the removal of 50 people or jobs from one node and the addition of 50 to some other node. Under these conditions, there are 100 possible configurations.

Figure 2. Flow diagram of search algorithms used to find improved urban spatial structures.

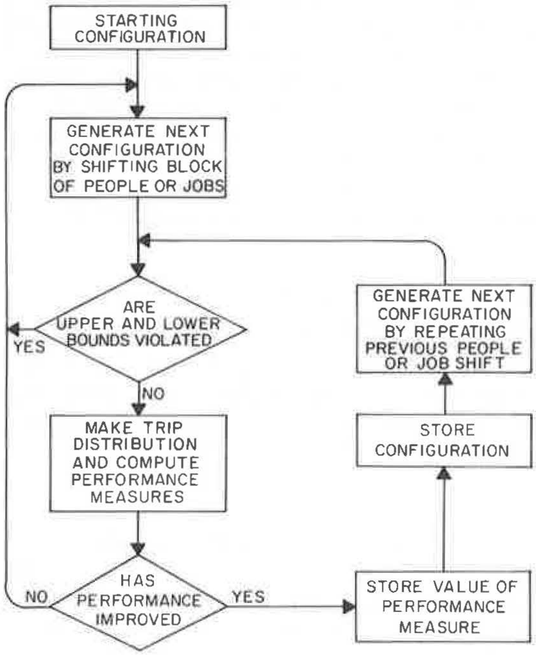


Figure 3. The 3-node network.

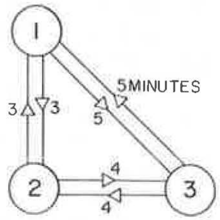
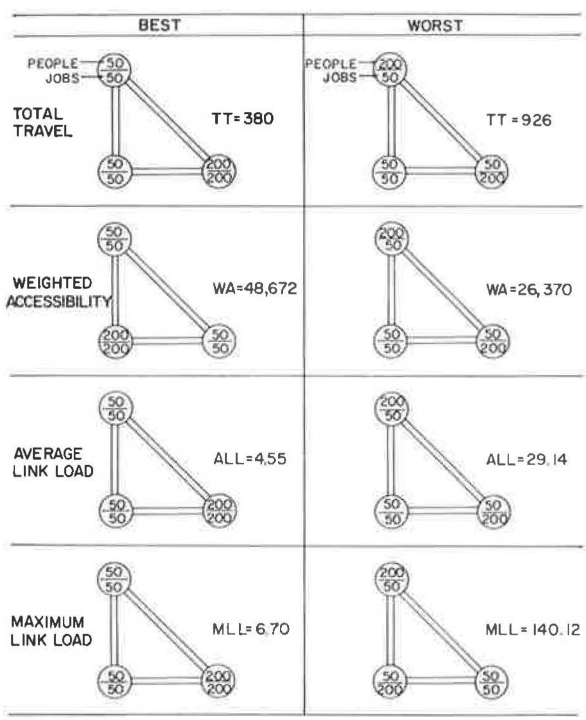


Figure 4. The best and worst people/job configurations for the 3-node network.



Each of the 100 configurations was generated and evaluated with the four performance measures. The best and worst configurations for each of the four performance measures are shown in Figure 4. As was expected, three of the four "best" configurations were identical, because a maximum concentration of people and jobs at the least central node will produce a minimum of total travel, a minimum average link load, and a minimal maximum link load. On the other hand, maximum weighted accessibility occurs when there is a maximum concentration of people and jobs at the most central node. In a similar vein, three of the worst configurations are identical in that a minimum number of people and a maximum number of jobs are located at the least central node, producing a maximum of total travel, a minimum weighted accessibility, and a maximum average link load. The largest maximum link load occurs when the two closest nodes are as unbalanced as possible (i.e., many people but few jobs).

With these results in hand, the next logical question was, "How often can the search algorithm find these best configurations?" Answers to this question are given in Table 1. Four different starting configurations were selected at random and the search algorithm was run 16 times, 4 times (from different starting conditions) for each of the 4 performance measures. As shown in Table 1, it was completely successful (i.e., it found the best configuration) only 2 of 16 times. However, when it did not find the best configuration, it did find one that was very nearly as good as the best, except in the case of average link load. Table 1 also shows how the average value of the 4 runs compares with the best value in each case. The differences are very small, with the exception of the average link load measure. These results were judged to be sufficiently encouraging to warrant a further round of testing with a 5-node network.

Experiment II: A 5-Node Network

The second series of tests of the search algorithm is similar to the first in that the algorithm was applied to a small network that had been previously completely enumerated. The difference is that the network configuration is slightly larger and more complex. Also, it is symmetric, as shown in Figure 5, and has a node that is clearly central, surrounded symmetrically by four others, which are equally least central. This experiment was designed to begin to approximate a symmetric urban configuration. As in the previous experiment, a pair of opposing one-way links connects each node pair and the intranodal distance, or travel time, was one unit.

A total of 400 people and jobs was distributed on this network, with a minimum of 50 people and jobs and a maximum of 200 people and jobs at any single node. Note that these limitations allow concentrations to be formed at any node but do not allow a uniform distribution over all the nodes.

Enumeration of the 5-Node Network and Experimental Results

An enumeration of all the possible configurations for the 5-node network was done with a step size of 50 for both people and jobs, producing a total of 1,225 configurations. In contrast to the 3-node network, enumeration of the larger 5-node network resulted in many sets of configurations that all had the same performance level. This is a direct result of the symmetry of the network. The best and worst of the 5-node network configurations are shown in Figure 6. Two of these best configurations are identical in that a maximum concentration at any one of the four least central nodes produces a minimum of total travel and a minimal average link load. Concentration of a maximum number of people and jobs at the most central node produces a maximum of weighted accessibility. The smallest possible maximum link load occurs when the people and jobs are dispersed as possible.

Three of the four worst configurations are identical. An unbalanced distribution of people and jobs (i.e., maximum people and minimum jobs) at two of the least central nodes produces a maximum of total travel, a minimum of weighted accessibility, and a maximum average link load. As before, when the two closest nodes are assigned a highly unbalanced people-job mix, the maximum link load occurs on the link that joins them.

How did the search algorithm perform on the 5-node network? Table 2 gives these

Table 1. Results of application of the search algorithm to the 3-node network from four different starting configurations.

Performance Measure	Success Ratio	Value of Best Performance	Average Value of Results of Four Searches	Average/Best
Total travel	2:4	380.00	380.5	1.00
Weighted accessibility	0:4	47,605.00	46,317.00	0.97
Average link load	0:4	6.70	10.45	1.56
Maximum link load	0:4	4.55	5.45	1.20

Figure 5. The 5-node network.

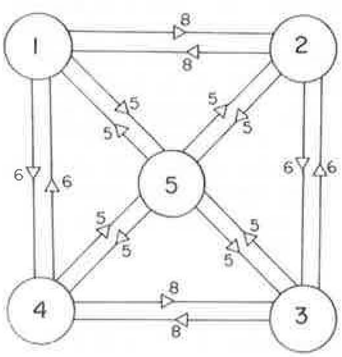


Figure 6. The best and worst configurations for the 5-node network.

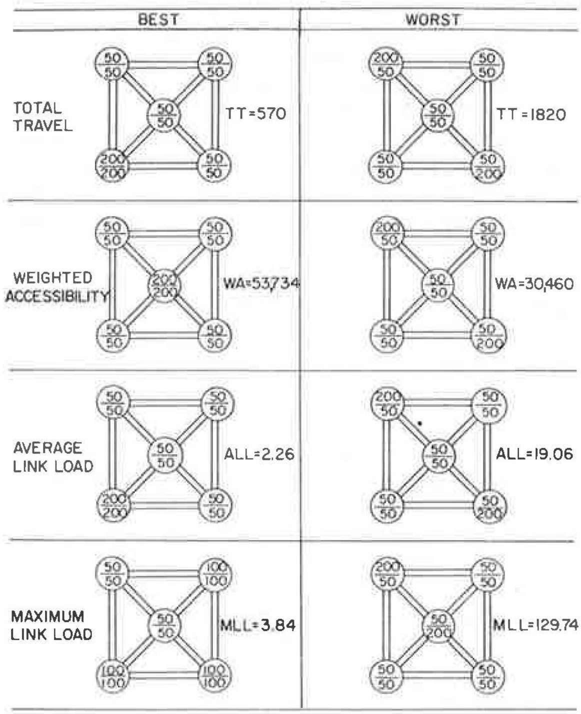


Table 2. Results of application of the search algorithm to the 5-node network from four different starting configurations.

Performance Measure	Success Ratio	Value of Best Performance	Average Value of Results of Four Searches	Average/Best
Total travel	4:4	569.70	569.70	1.00
Weighted accessibility	0:4	52,735.00	52,740.00	1.00
Average link load	0:4	5.44	5.66	1.04
Maximum link load	4:4	2.26	2.26	1.00

results. While the search algorithm found the best configuration only 8 of 16 times, it did find near-optimal configurations on all 16 tries. This result is shown in Table 2 by the very close correspondence between the average value of the 4 runs and the best value for that run in all 4 categories. These results were judged to be satisfactory enough to continue the test of the search algorithm using a 12-node network.

APPLICATION OF THE SEARCH ALGORITHM TO A SIMPLIFIED 12-NODE NETWORK REPRESENTING THE WESTERN PART OF KING COUNTY, WASHINGTON

The purpose of the third experiment is to use the search algorithm on a reasonably realistic network to investigate the effect on travel requirements that could be obtained by altering an existing urban spatial structure. To study this problem, a simplified network representation of the western part of King County was developed. This 12-node, 38-link network is shown in Figure 7. Several of these nodes represent the city of Seattle while the others represent surrounding suburban communities. Population and employment data for 1970 were developed for each node by aggregating 1970 census tract data for King County. The total population allocated among the 12 nodes is 941,000 people and the total employment is 478,000 jobs. The question to be addressed is, "How might we rearrange these people and jobs among the 12 nodes so as to substantially reduce the travel requirements of the system while maintaining a high level of accessibility?" Our approach to this problem is as follows:

1. Define a best and worst urban spatial structure for each of the four performance measures. Use these configurations to establish upper and lower bounds (i.e., a scale) for the investigation.
2. Calculate the travel requirements of the 1970 spatial structure and a uniform spatial structure (i.e., equal numbers of people and jobs at each node) to compare with the results of the search algorithm.
3. Use the search algorithm to find a good spatial structure for each of the four performance measures.
4. Determine the travel requirement reduction associated with each of the four spatial structures found by the search algorithm in relation to the 1970 base.

The results of each of these steps will be briefly discussed in turn.

Estimation of a Best and Worst Urban Spatial Structure for Each Performance Measure

Table 3 shows that the best and worst results for the 3-node and 5-node cases have quite distinct characteristics. These same characteristics were used to estimate the best and worst configurations for the 12-node case. For example, the best 3- and 5-node configurations for the weighted accessibility performance measure were found by assigning a maximum, balanced, people/job level to the most central node while placing a minimum number of people and jobs at all other nodes. The same logic was assumed to hold in the 12-node case. Other best and worst configurations were similarly determined by following the logical rules of Table 3. The range of performance between these best and worst configurations provides a scale that can be used to compare various configurations. This scale is shown in Figure 8 and is discussed in the following section.

Results of the Calculation of the Performance of the 1970 Spatial Structure and a Uniform Spatial Structure

The comparative performance of the 1970 spatial structure is shown in Figure 8. As can be seen, the 1970 system is within 25 percent of the best possible performance in all categories except weighted accessibility. These results suggest that our present urban configuration might not be as inefficient as the various critics of the American city would have us believe. These measures also suggest that the largest potential for improvement is in the total travel and weighted accessibility categories. For comparison purposes, a uniform spatial structure was constructed, and its performance is also plotted in Figure 8. The uniform spatial structure has an equal number of people

Figure 7. The 12-node network representation of western King County, Washington.

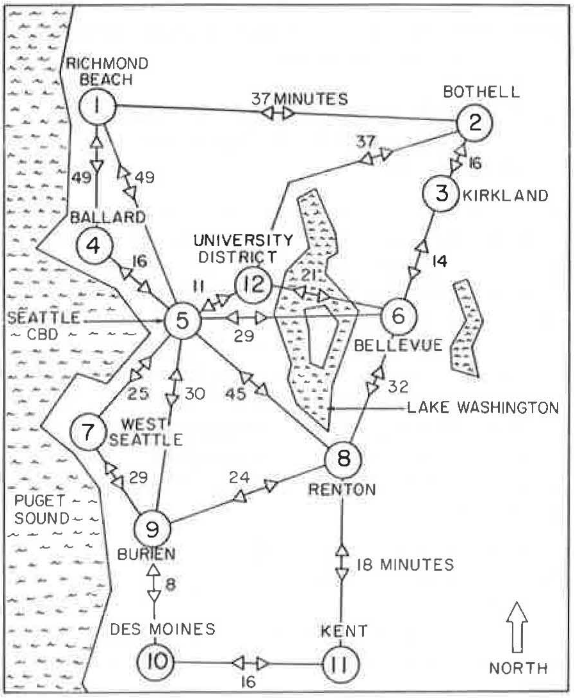


Table 3. Definition of best and worst configurations for each of the four performance measures.

Performance Measures	Configurations: Best[a]	Worst[b]
Total travel	Maximum people and jobs at least central node, minimum people and jobs at all other nodes, remainder at second least central node	Maximum people, minimum jobs at least central node, minimum people and jobs at all other nodes, remainder at second least central node or node as far removed from least central node as possible
Average link load	Same as total travel	Same as total travel
Maximum link load	Same as total travel	Maximum people and minimum jobs at two closest nodes
Weighted accessibility	Maximum people and jobs at most central node, minimum people and jobs at all other nodes, remainder at second most central node	Same as total travel

[a]Minimum total travel, average link load, maximum link load, and maximum weighted accessibility.
[b]Maximum total travel, average link load, maximum link load, and minimum weighted accessibility.

Figure 8. Comparative performance of alternate urban spatial structures.

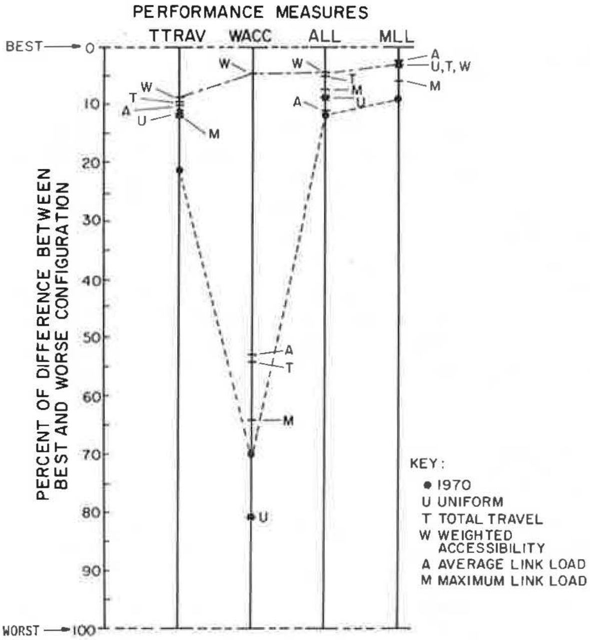


Table 4. Comparison of alternative urban configurations with the 1970 base configuration.

Configuration	Percent of People Moved	Percent of Jobs Moved	Percent Reduction/Increase of 1970 Performance: Total Travel	Weighted Accessi-bility	Average Link Load	Maximum Link Load	Sum of Nodal People/Job Ratio Deviations From 1.97
1970 base	0.0	0.0	n.a.	n.a.	n.a.	n.a.	52.5
Best configuration (total travel, average link load, maximum link load)	84.6	94.0	-66	n.a	-91	-87	0.03
Best configuration (weighted accessibility)	75.2	55.8	n.a	+243	n.a.	n.a.	0.03
Uniform	22.2	55.2	-46	-35	-27	-76	0.0
Search result I (total travel)	36.0	36.7	-54	+51	-51	-57	12.5
Search result II (weighted accessibility)	56.5	33.5	-61	+222	-78	-54	16.6
Search result III (average link load)	40.1	37.7	-53	+55	-36	-25	12.8
Search result IV (maxi-mum link load)	23.8	25.6	-43	+20	-34	-63	5.6

and an equal number of jobs located at each node. As can be noted, a uniform spatial structure is better than the 1970 situation in all categories except weighted accessibility, where it performs quite poorly.

Utilization of the Search Procedure to Find Good Configurations for Each Performance Measure

For the search process, the upper and lower limits on people located at any single node were set at 600,000 and 2,000. The bounds on jobs at any node were set at 300,000 and 1,000. In both the people-shifting and job-shifting phases of the search process, a step size of 1,000 was used. The 1970 configuration was used as the starting condition for all four searches. The results of these four searches are shown in Figure 8. As can be seen, the search procedure found configurations that were substantially better than the 1970 situation in all cases. Configuration W, which was found by using weighted accessibility as the single objective, is the best of these four configurations in three of the four performance categories and is the best spatial structure found by the search procedure in relation to all four performance measures. In no case did the search procedure find one of the four best configurations.

Travel Requirement Reductions Associated With the Alternative Spatial Structures in Relation to the 1970 Base

Table 4 gives the proportion of people and jobs that would have to be moved to other locations for the best, uniform, and each of the four search configurations in relation to the 1970 base. It also shows the percentage reduction of each of the three travel performance measures and the percentage improvement of the accessibility performance measure for each alternative configuration in relation to 1970 as a base. Table 4 shows that very large changes in the current urban structure would be required to achieve the best configuration. Although changes of this magnitude are clearly infeasible, even in 20 to 30 years' time, they do provide a type of upper limit in terms of what might be ultimately possible insofar as travel requirement reductions and maximization of accessibility are concerned. The uniform configuration requires far fewer people and job location shifts and is associated with substantial improvements in all performance measures except accessibility, which is worse than the 1970 level. Most interesting are the results of the four search runs. Very generally, these results indicate that by moving about a third to a half of the people and about a third of the jobs, reductions in total travel, average link load, and maximum link load of about 50 percent or more (below 1970 levels) could be expected. Increases in accessibility of from 20 percent to 220 percent could also be expected. These are very substantial reductions but would also involve quite large structural changes in the current urban pattern.

Changes in an existing urban structure of this magnitude are certainly not feasible in the near future (5 to 10 years), yet most large cities will probably grow by this much during the next 20 to 30 years. If this growth could be guided into appropriate locations, then we might experience a concurrent growth in transportation requirements that would be far less than might occur in a laissez faire situation where present trends were continued unchanged into the future.

Another way of describing the difference between the 1970 spatial structure and the five alternative spatial structures is to examine the balance between people and jobs at each node in the network for each case. The people/job ratio for the study area is 1.97. In the uniform distribution, the people/job ratio in each node is therefore 1.97. If we sum the differences between the people/job ratio at each node and 1.97, we obtain a rough index of how "balanced" a particular configuration is. The closer this index is to 1.97, the greater is the balance between people and jobs at each node in the network. These data are shown in the right-hand column of Table 4. They show that the land use balance index of each of the configurations found by the search algorithm is much closer to 1.97 than is the 1970 base. This means that the balance of people and jobs at each location in the system is a key factor in restructuring urban areas so as to reduce their transportation requirements.

CONCLUSIONS AND RECOMMENDATIONS

Our conclusions will address two questions: "How useful is the analytical approach used in the study?" and "What are some possible policy implications that can be derived from our results?"

Utility of Analytical Approach

This study has demonstrated that a simple search algorithm can be a useful tool for finding spatial structures that have desired characteristics. More powerful and reliable algorithms are needed because our simple algorithm performed only reasonably well on problems with known optimal solutions. The complexity of the search algorithm will undoubtedly have to be increased as the size and complexity of the problem increases. Most useful would be a search algorithm that will look for configurations that are better with regard to some combination of performance measures rather than for only one performance measure at a time.

The alternative to using a search algorithm is the fabrication of alternative spatial structures in one's mind. It is certainly possible that one could construct an adequate sample of all possible configurations judgmentally or by following systematically some logical decision rules. One would need to conduct a series of experiments along these lines before any definite conclusions on this issue could be reached. Until it can be shown that judgmental searching is more cost-effective than computer-directed searching, it seems reasonable to continue the development and testing of search algorithms for urban systems design problems.

Some Policy Implications of the Experiments

It has been shown that some dramatic reductions in travel requirements could be achieved by altering urban spatial structure. By logical extension, it has been argued that by guiding the growth of a city it should be possible to substantially reduce its needs for travel and transportation facilities and services relative to those that would result if present trends in growth patterns continued unchanged into the future. It has also been shown that substantial improvements in accessibility can be achieved by altering an existing spatial structure. However, these results have been derived using a very simplified representation of a real-world urban system and by using a very simple predictive model to generate estimates of the travel requirements of various urban configurations. This means that our results must be interpreted with caution and represent only a rough idea of the potential of altering urban spatial structure to reduce the need for transportation in our cities.

What appears to be most needed at this time is a way of identifying those particular locations where it would be most beneficial to encourage new people or jobs to locate. If such locations could be identified, public programs and policy could then be oriented to encouraging growth to occur in locations where the associated transportation requirements would be minimal. Other complementary programs oriented to the encouragement of particular changes in the existing urban structure could also be formulated with the aid of such a technique. Such a program would typically specify several locations where increases or decreases of residences and/or jobs would do the most good in terms of reducing future travel requirements as well as maintaining a high level of accessibility. The development of such a technique is high on our list of priority research tasks and will be the subject of a future research report.

ACKNOWLEDGMENTS

This paper is based on an unpublished Master of Science in Civil Engineering thesis by Joseph R. Beck. This thesis, completed in 1972, was edited and extended during the early part of 1973 by J. B. Schneider and James Clark.

This report was produced as part of a Research and Training Program in Urban Transportation sponsored by the Urban Mass Transportation Administration of the U.S. Department of Transportation. The results and views expressed are the independent products of university research and are not necessarily concurred in by the Urban Mass Transportation Administration.

REFERENCES

1. Doxiadis, A. D. Emergence and Growth of an Urban Region: The Developing Urban Detroit Area. Detroit Edison Co., 1966.
2. Einsweiler, R. C. A Case Study: Twin Cities—Mass Transit as a Factor in Metropolitan Planning. In Urban Mass Transit Planning (Homburger, W. S., ed.), Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, 1967.
3. Goldman, M. A Man-Computer Graphics System for the Evaluation of Transportation Impacts of Alternative Urban Spatial Structures. Unpublished Master of Science thesis, Dept. of Civil Engineering, Univ. of Washington, 1972.
4. Harris, B. The City of the Future: The Problem of Optimal Design. In Papers of the Regional Science Association (Thomas, M. D., ed.), International Academic Printing Co., Tokyo, Vol. 19, 1967.
5. Hemmens, G. C. Experiments in Urban Form and Structure. Highway Research Record 207, 1967, pp. 32-41.
6. Urban Transportation Research and Development. National Academy of Engineering, Committee on Transportation.
7. Rapp, M. H. Planning Demand-Adaptive Urban Public Transportation Systems: The Man-Computer Interactive Graphic Approach. Urban Transportation Program, Univ. of Washington, Research Rept. 71-4, 1972, 203 pp.
8. Scott, A. J. Combinatorial Programming, Spatial Analysis, and Planning. Methune and Co., London, 1971.

DISCUSSION

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Schneider and Beck suggest that it is feasible to attempt to reduce travel requirements in an urban area by a long-term restructuring of the city's spatial patterns. Certainly to judge by their conclusions there is great potential in such an approach to the urban transportation problem. The purpose of this discussion is to suggest that further studies of this topic must (a) give closer scrutiny to the performance measures used to judge urban spatial configurations, (b) find better search algorithms and means for evaluating them, and (c) employ clearer techniques for presenting results and assessing the potential of urban restructuring.

PERFORMANCE MEASURES

The authors state that investigations of land use-transportation relationships should be capable of answering the question, "What are the transportation criteria with which we can evaluate alternative land use patterns?" They do not return to this question, despite the fact that their own findings provide sufficient data to answer it for at least two of the four performance measures applied in the study.

With respect to its centrality to the study, the more important of these two measures is the weighted accessibility measure. It appears to be used as a surrogate for mobility, but the results suggest it is not a good one, and other considerations support that contention. Early in the paper Schneider and Beck state that they wish to find urban configurations that "(a) result in equal or better individual mobility and (b) produce a better level of environmental quality in the city." In the application to the Seattle area, this is translated as "substantially reduce the travel requirements of the system while maintaining a high level of accessibility." However, their results (Fig. 8) indicate that the 1970 Seattle spatial structure did not have a particularly high level of accessibility. In fact, its score is closer to the worst possible level than to the best. Yet they surely imply that mobility in the area is good.

Figure 8 also shows that the 1970 spatial pattern in Seattle performs well on the three other measures. One inference might be that these three are reasonable measures of the way people choose to behave but that the measure of weighted accessibility does not correspond to any form of present locational behavior. Closer examination of this measure supports at least the latter part of the inference. Their accessibility measure is a function of separation between all homes and all employment in the area. More likely, individuals locate with respect to only one job, but also with respect to various cultural, recreational, or environmental amenities that are not present in this particular measure. Hence to rely on it as a justification for restructuring an urban area seems dubious at best.

The other performance measure that can be assessed is that pertaining to the maximum link load. The authors suggest that large maximum loads may be either desirable (permitting high-capacity fixed route systems) or undesirable. They then assert that they wish "to find urban configurations that do not require high-capacity transportation facilities", so that the presence of a high maximum link load is taken to be a negative feature. This seems rather arbitrary, considering the ambiguity of the measure. The findings suggest it adds nothing to the identification of good configurations. (Figure 8 indicates that spatial configurations that perform well on other measures also tend to have low maximum link loads.) It therefore seems reasonable to omit this measure.

A replacement for it might be a measure relating to the amount of construction of new facilities required for any particular urban spatial configuration. It makes little sense to decrease total travel in a region if the bulk of this reduced travel is anticipated to take place along routes that are at present of very low capacity. This appears to be the kind of minimum travel solution to which several of the performance measures would lead, with the bulk of the people and jobs in the least accessible location. Would the existing transportation facilities be adequate to deal with such redirected traffic? Should this not be one of the primary criteria for a revised urban structure?

SEARCH ALGORITHM

The authors state that their study is primarily intended to examine the assertion that the combinatorial space representing urban structures is not smooth and that "any search procedure that attempts to find 'best' combinations on the basis of gradients would likely be ineffective." Their conclusions state that their simple search algorithm is useful but that better algorithms are needed. They do not refer to the assertion they claim to be examining, but the implication is that gradient-based searches can be effective.

However, data from their applications of the algorithm suggest that the algorithm is not particularly effective and hence that the assertion is reasonable. Figure 8 provides the clearest demonstration of the algorithm's failings. The urban structure with the highest weighted accessibility also gave the best algorithm-determined values for two other measures. That is, when attempting to minimize total travel explicitly, the algorithm did not arrive at as good a total travel figure as it did while minimizing a different measure. This failing is even more apparent for the maximum link load measure. Here every other application of the algorithm (i.e., to optimize each of the remaining three measures) produced a better value for the maximum link load than did the run in which it was directly optimized.

Clearly there exists a better logic for a search algorithm. The authors use heuristics derived from their first two tests to construct "best" and "worst" configurations. As this procedure produces a solution roughly 5 to 10 percent better than anything the search algorithm found, it would seem reasonable to reject the algorithm and devise a new one based on the heuristics described in Table 3.

RESULTS

Schneider and Beck conclude that "dramatic reductions" in travel could be accomplished by restructuring urban spatial patterns. However, they present their findings about the potential for improvement in a rather curious way. They state that reductions "of about 50 percent or more (below 1970 levels)" can be expected from moving roughly a third of the people and jobs in the Seattle area. But this reduction is not in terms of actual 1970 travel levels; rather, it is in terms of differences between the 1970 value and the best possible. To clarify what is meant, let X represent the best possible value and Δ the difference between the best and the worst. Then, reading approximate values from Figure 8,

$$\text{Total travel (1970)} = X + 0.22\,\Delta$$

and

$$\text{Total travel (T structure)} = X + 0.10\,\Delta$$

For this value of T-structure total travel to represent a 54 percent reduction from the 1970 total travel, Δ must be roughly 450 times the size of X. That is, the worst possible value of total travel must be more than 450 times as great as the best value. Although they do not supply actual numbers, it seems unlikely that this is the case: In the 3- and 5-node problems, the ratios of worst to best were 2.4 and 3.2 respectively. Using a similar magnitude for an example, a worst-to-best ratio of 10 in the Seattle problem would imply a reduction in total travel of about 36 percent of the 1970 level. While this is not as impressive as their 54 percent figure, it still represents a sizable amount of travel. Expressing potential reductions in terms of present conditions would provide a number that is simpler to understand and forms a more reasonable basis for decisions. Further, it would be a much stronger indicator of the importance of any future studies of urban restructuring.

AUTHORS' CLOSURE

Professor Hall's discussion suggests that further studies of this topic are needed. We fully agree and are presently engaged in such work. Beyond this, however, we find that his comments are either misdirected or are based on a mistaken interpretation of our results. Initially, he discusses the performance measures used to gauge the travel requirements of alternative urban spatial structures. His suggestion that the accessibility measure used could be improved by considering access to other than workplaces is good and we concur. This was done by Hemmens in a study we referred to conducted in 1966. Our reason for using only workplace access is that all available empirical evidence to date suggests that access to workplace is a far more important determinant of residential locational choice than is access to other nonwork activities. Our reason for interpreting high link loads as being undesirable was not arbitrary. Instead, it is based on the general philosophy of the paper, which is that we were seeking nontransportation solutions to current transportation problems. We stated our preference for the "no-build alternative" early in the paper, but this was apparently overlooked by Hall. His suggestion that an additional indicator related to "new construction required" is needed also fails to recognize the theme of our investigation.

The difficulties we experienced with the search algorithms were clearly stated by us and are only reemphasized by Hall. We have made no claims that the search algorithm we used is highly effective and we note in our conclusions that a better search algorithm is needed. Since this paper was written, we have developed an algorithm that uses a gradient search procedure, and it is now operational. Initial tests have shown that it is much more effective than the one used in the investigation being discussed here. Our purpose in this paper was to take a quick and rough cut at the problem, and this meant that extensive work on refining the algorithm could not be justified. The algorithm worked sufficiently well for us to produce results that we feel are encouraging enough to warrant a second cut at the problem. This investigation will be more detailed, rigorous, and elegant.

Hall's claim that our results are computed improperly is based on his mistaken interpretation of them. Our general conclusion that substantial reductions in travel could be accomplished by restructuring the city is not derived from the data presented in Figure 8, as Hall asserts. They were calculated using the 1970 situation as a base, and this is clearly indicated in Table 4. We feel that our conclusions, while derived from a crude, macro-scale analysis, are sufficiently encouraging to warrant further investigation of this topic, and there is nothing that Hall has included in his comments that gives us any reason to think we are not pursuing a proper course of action.

CORRELATION OF SOCIOECONOMIC FACTORS WITH CORRIDOR TRAVEL DEMAND

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Current interest in public transit to alleviate the urban transportation problem requires more research about the effects on urban structure of new modes. The purpose of this paper is to examine one aspect of this: the internal relationships between the socioeconomic characteristics of commuters and the transportation service characteristics they value in their mode choice to work. Specifically, the study is concerned with (a) the correlation of selected socioeconomic factors of individuals with their choice of travel attributes and (b) the effect of socioeconomic factors in causing car drivers to shift mode. Canonical correlation analysis illustrates that each modal group using a transportation corridor has unique socioeconomic characteristics and that these are related to the attributes of the transportation system. Car drivers are less dependent on system attributes than bus riders, and therefore planned changes in the system (such as the introduction of rapid transit) will have less effect on this group than on bus users in terms of use of the system. There is also some indication that changes in bus frequency would have an effect on car ownership in a given corridor. Statistical tests, using discriminant analysis, on a subsample of automobile drivers indicates that the socioeconomic characteristics of an individual probably exert an influence on his tendency to shift mode and on his sensitivity to specific transportation service level changes in the system. In particular it was found that as income levels increase the tendency to shift mode decreases. The findings of the study have implications for mode split planning, travel demand modeling, and urban structure.

•CURRENT interest in public transit as a means to rationalize urban transportation requires a better understanding of the effects of new modes on both travel generation and modal split. The purpose of this paper is to examine one aspect of this problem: the interdependent relationship between the socioeconomic characteristics of commuters in a travel corridor and the attributes of the transportation mode serving the corridor. The findings have implications for mode split, travel demand, and—indirectly—corridor development.

Research into mode split has shown that there are two major influences on the mode choice: (a) the socioeconomic makeup of the traveler and (b) the transportation system characteristics such as travel time, travel cost, and convenience. Early mode split methods can be grouped into those that were based primarily on the first of these influences and those that were based on the second (1). In the evolution of later mode split methods, the influence of income and car ownership has been considered by inference in the interpretation of model results (2). But by and large the variables used in recent models are primarily measures of transportation system characteristics, which permit the prediction of mode split when the magnitude of these variables is changed in a way that would simulate new modes. This process appears sound, given the assumption implicitly held in mode split analysis: that the introduction of a new mode has no effect on the absolute number of tips demanded but only on the mode split.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

But what happens if this assumption is released? Indications from land use modeling studies are that a change of accessibility in a travel corridor will have some effect on land use activity, usually defined by the changes in population and employment structure in the urban region. This implies a change in travel demand—and a change in the socioeconomic structure of a transportation corridor—with the introduction of a new mode. Several authors have addressed this problem in the form of travel demand modeling, including Kraft and Wohl (3), Domencich, Kraft, and Valette (4), Brand (5), and Manheim (6). The thrust of the work of these authors is that travel demand is a derived demand based on the desire for activities at trip destination. Therefore, travel demand is a function of land use activities and transportation service. The essential structure of the early demand models (3, 4) included the classic urban transportation planning submodels of trip generation, trip distribution, and mode split. But the effect of transportation service on trip generation and trip distribution was not included in these early models. More recent studies have attempted to consider this feedback effect by general equilibrium models that model both travel flow and land use effects as a set of equations to be solved either simultaneously (5) or sequentially (6).

As a by-product of the mode split and travel demand modeling effects, inferences have been made about the effects of socioeconomic variables as well as the system variables in the demand function. However, for future operational travel demand models, including the feedback loop, our level of understanding of the internal structure of travel decisions and travel demand dimensions needs to be improved. This paper is an attempt to explore the internal structure of demand as it relates to urban structure changes and the mode split. The objectives of the research are (a) to assess the explicit relationship between socioeconomic characteristics of commuters and choice of system characteristics in the journey to work and (b) to determine what potential influence socioeconomic characteristics have in causing an individual to shift to a new mode.

The study method is an empirical analysis of a sample of automobile drivers and bus passengers of a commuter travel corridor with destinations in the central business district of Vancouver, Canada. The commuter-shed used in the analysis is in most important respects a typical high-income suburban area with some high-density residential districts. Incomes, car ownership rates, and occupational status are higher than for the region as a whole. The mode split in the corridor is about two-thirds automobile and one-thirds bus commuting. The mean travel time for automobile drivers is 31 minutes, and for bus commuters it is 37 minutes.

INTERDEPENDENCE OF SOCIOECONOMIC AND TRANSPORTATION SYSTEM ATTRIBUTES

If a travel corridor undergoes population structure changes with a change of accessibility, a knowledge of the cause-effect linkages is important to assess the specific impact of a new mode. The assumption is that equilibrium exists in a travel corridor between the type of people who commute and the characteristics of the transportation system. For example, if a corridor is served by a toll freeway that gets commuters to work quickly, the freeway will over the long run attract people to its influence area who are highly sensitive to travel time savings in the journey to work vis-à-vis the population as a whole. On the other hand, a corridor served by public transit, if travel costs are low, may attract people to its influence area who are cost-sensitive. In practice a travel corridor would likely have at least two influence areas, each of which would be defined as the group of persons who use a specific mode. It is probable that persons of any specific mode group are similar types and that this group will differ from other mode groups in important ways. It is also probable that members of each mode group will value alike the attributes of the transportation alternatives available and choose that combination of attributes (i.e., mode) that minimizes his level of dissatisfaction. In contrast, the members of a different mode group will select a somewhat different set of attributes. If there is an interdependence between the socioeconomic factors of a mode group and the travel attributes of the mode, and if the nature of this interdependence changes from mode group to mode group, we can begin to predict the socioeconomic composition of a transportation corridor if a new mode (i.e., a new set of transportation attributes) is introduced. The primary implication of this approach is that urban development models can be formulated on a disaggregated behavioral basis to follow sequentially the behavioral transportation flow models now in use.

Preliminary Data Analysis

The data matrix consisted of 1,244 car drivers and 967 bus passengers. Twelve variables representing the socioeconomic and transportation characteristics of the sample were available for analysis. The variables were divided into two sets of six: $X^{(S)}$, representing the socioeconomic characteristics, and $X^{(T)}$, representing the transportation system characteristics. Set $X^{(S)}$ consists of age (AGE), occupation (OCC), the number of times per week a car is necessary at work (CNEC), car ownership (COWN), family income (INC), and the availability of a car for the work journey (CARA). Set $X^{(T)}$ consists of travel time at origin of trip (TTO), travel time at destination (TFRM), total travel time (OTT), out-of-pocket expenses for either parking charge or transit fare (OPE), OPE divided by income (E/INC), and bus frequency at origin (FREQ). A full description of the variables used in the analysis is in the Appendix.

Chi-square tests of comparable variables (Table 1) indicate there are two distinct socioeconomic groups associated with the two modes. For each mode, group socioeconomic characteristics are relatively homogeneous compared to the difference in characteristics between modes. Commuters in the prime working age groups of 40 to 60 are car-oriented while younger and older age groups are bus-oriented. Indications are that substantial commuters in the 20 to 40 age group prefer the bus. Occupational structure is related to mode choice somewhat differently than expected in that a high proportion of managers and professional employees use the bus. Also, a substantial proportion of unskilled workmen and clerical employees—groups that are often thought to be transit "captives"—are car-oriented. Secretaries and sales workers are transit-oriented as expected. Car ownership is high in this case and may be expected to moderate the usually high correlation between car ownership and mode split. Income shows the expected trend, with high-income households associated with car mode and low-income ones with bus use.

Statistical Analysis

Canonical correlation analysis was used to investigate the relationship between the socioeconomic variables of each mode group and transportation system variables. This technique gives an optimal weighting and combination of the socioeconomic variables so that the combination will maximally correlate with the best combination of the transportation system variables. It tells us how the two sets of variables are related to each other and how the variables within each set contribute to this relationship. The conceptual implication is that an individual of a particular socioeconomic makeup will choose that combination of transportation service attributes that, in combination, minimizes his travel dissatisfactions. By looking at each mode group in turn we are able to interpret those characteristics of the group that are dominant in the mode choice. In this way socioeconomic-transportation system interdependence is analyzed as a system of attributes and not as a series of suboptional relationships inherent in a multiple-regression approach.

Canonical correlation brings out the nature of the interdependence of the two sets of variates when the linear combination of the two sets is maximally correlated. Consider an arbitrary linear combination $U = \alpha' X^{(S)}$ of the socioeconomic variates and an arbitrary linear combination $V = \gamma' X^{(T)}$ of the system variates. The maximum correlation is found by rotating the reference axes for each set of variates in the test space so that the axes of the socioeconomic variate set and those of the transportation service variate set form a new axes system. If the parameters α and γ are normalized such that U and V have unit variance, then

$$\Sigma U^2 = 1 = \Sigma \alpha' X^{(S)} X^{(S)'} \alpha$$

and

$$\Sigma V^2 = 1 = \Sigma\gamma' X^{(T)} X^{(T)'} \gamma$$

The correlation between U and V is, therefore,

$$\Sigma UV = \Sigma\alpha' X^{(S)} X^{(T)'} \gamma \quad (1)$$

because

$$\Sigma X^{(S)'} \alpha = 0 \text{ and } \Sigma\gamma' X^{(T)} = 0$$

Thereby, substituting in Eq. 1, the correlation between the two sets is

$$\Sigma UV = \alpha' R_{12} \gamma \quad (2)$$

The canonical correlation problem is to find the values of α and γ when ΣUV is maximized, i.e., when the derivative of ΣUV with respect to α and γ is zero. Anderson (7) has shown that ΣUV is maximized when

$$\begin{bmatrix} -\lambda R_{11} & R_{12} \\ R_{21} & -\lambda R_{22} \end{bmatrix} \begin{bmatrix} \alpha \\ \gamma \end{bmatrix} = 0 \quad (3)$$

in which

R_{11} = intercorrelations among the socioeconomic variates,
R_{22} = intercorrelations among the system variates,
R_{12} = intercorrelations of socioeconomic with system variates,
R_{21} = transpore of R_{12}, and
λ = latent root, or eigenvalue.

The determinantal equation of the first term

$$| R_{22}^{-1} F_{21} R_{11}^{-1} R_{12} - \lambda I | = 0 \quad (4)$$

is solved for all possible values of λ. For each characteristics root, the vectors of the coefficients α and γ are found for the set U and V from the canonical equations

$$(R_{22}^{-1} R_{21} R_{11}^{-1} R_{12} - \lambda_1 I)\gamma = 0 \quad (5)$$

and

$$\alpha = (R_{11}^{-1} R_{12}\gamma)/\lambda_1 \quad (6)$$

where α gives the weighting of each of the socioeconomic variables in the interdependent relationship and γ gives the weighting of each of the transportation system variables in the relationship.

A measure of the statistical significance of any canonical correlation is given by R_c, which is the correlation between any weighted linear combination of one set of variables and any weighted linear combination of the second set of variables. In geometrical terms it is the cosine of the angle between the vectors representing each set of variables. If the two vectors are coincident, $R_c = 1.0$, indicating that the two sets of variables are perfectly correlated. Significance level of any R_c is a χ^2 test of its significance in extracting the relationship between any two sets of variables.

Since the sets of variables may be correlated in several ways, several canonical vectors are possible, each correlation being given by R_{c_1}.

Results of Correlation Tests

Table 2 shows one significant way in which the two sets of variables are interrelated. The result of the test shows reasonably strong association ($R_{c1} = 0.71$ and $p < 0.001$) between income, out-of-pocket expenses, and CBD walking distances, as demonstrated by the value of the coefficients. The test implies that high-income automobile commuters pay relatively high parking rates. However, in terms of their ability to pay, high-income workers pay a smaller proportion of their income to park than low-income workers. It is also evident that the relatively high parking cost is offset by a shorter walking distance. Therefore, as we would expect, commuters who can afford it park closer to their destination, at higher cost, to avoid walking.

It is useful also to examine a second way in which the variables are correlated as shown by Table 3. This table gives the vectors of coefficients for a second important dimension that is statistically independent, or orthogonal to the first set of vectors. This variate extracts the correlation between the other characteristics besides income and shows the effect of bus frequency. It shows that younger people of low occupational and car ownership status, for whom a car is seldom necessary for their work or not easily available, are concerned primarily with bus frequency. This implies that people of this general type locate where there is good bus service, even though they are, in this instance, car drivers. People of this group also park further from their job location, indicating their inability to command close-in parking spaces. In essence, these are low socioeconomic status car commuters who nevertheless need good bus service as a viable alternative, either because they cannot afford a second car and want good bus service for other members of the family or because they perhaps need to commute by bus periodically.

Tests on the bus group show results similar to the car group with some important differences. Table 4 gives a canonical correlation between income and cost factors. However, the linkage is not as strong as with the car group, particularly with transit fare. The ability to pay variable (E/INC) shows a fairly strong negative correlation, but since fares are relatively constant for all users, the correlation is probably increased because the test is showing the correlation between income and the increase of income in the E/INC variable. The simple correlation between these two variables (i.e., INC and E/INC) separate from all other variables is $r = -0.86$. It also appears from the table that older bus commuters seek a relatively short walking distance at trip destination.

The second important correlation between sets of variables among the bus commuters as given by Table 5 also shows the concern of those of low car ownership and availability to locate where there is good bus service. The test also shows a concern with transit fare. It also shows that older people place greater emphasis on efficient transit service than do younger bus users.

One inexplicable result of the canonical correlation tests is the absence of a significant correlation of income and total travel time. A separate analysis of variance test was carried out to find an explanation for this.

Income and Travel Time Correlation

Table 6 gives the variation of incomes and travel times by mode. There is some indication that as income increases travel time by car increases and travel time by bus decreases. However, variance ratios show no significant variation in travel time either by mode or by income. While substantial differences appear to exist in modal travel times, when income is considered the differences in travel time are due mostly to the income factor. This finding is supported by the work of Zupan (8) and Domencich, Kraft, and Valette (4), who conclude that socioeconomic variables are more important than the system travel time savings between modes in determining mode choice.

In the case under study this explanation appears reasonable since the travel time variation across the whole sample was relatively narrow, with most trips taking between 20 and 45 minutes. Further tests with a broader range of trip lengths are needed to show the relative importance of travel time and travel cost factors.

Table 1. Significance test of statistical difference in socioeconomic characteristics between car drivers and bus riders.

Socioeconomic Characteristic	d.f.	χ^2	p[a]
Age	3	87.5	p < 0.001
Occupation	5	407.4	p < 0.001
Car ownership	3	385.4	p < 0.001
Income	3	482.1	p < 0.001

[a]p = probability of there being no difference in mode group for variable shown.

Table 2. First canonical correlation test of the interdependence between socioeconomic and transportation system characteristics for car drivers.

Variables of Set 1	Coefficients (α)	Variables of Set 2	Coefficients (γ)
AGE	0.0214	TTO	-0.0543
OCC	0.0065	TFRM	-0.1007
CNEC	0.0758	OTT	0.0367
COWN	-0.0363	OPE	1.6829
INC	0.9880	E/INC	-1.7666
CARA	0.1617	FREQ	0.0063

Significance test: $R_{c_1} = 0.71$; $\chi^2 = 925.88$; d.f. = 36; $p < 0.001$.

Table 3. Second canonical correlation test of the interdependence of socioeconomic and transportation system characteristics for car drivers.

Variables of Set 1	Coefficients (α)	Variables of Set 2	Coefficients (γ)
AGE	-0.5591	TTO	-0.1770
OCC	-0.2481	TFRM	0.2499
CNEC	-0.4512	OTT	-0.1206
COWN	-0.5526	OPE	0.0835
INC	0.1893	E/INC	0.1893
CARA	-1.2391	FREQ	0.9740

Significance test: $R_{c_2} = 0.17$; $\chi^2 = 45.61$; d.f. = 25; $p < 0.01$.

Table 4. First canonical correlation test of the interdependence between socioeconomic and transportation system characteristics for transit riders.

Variables of Set 1	Coefficients (α)	Variables of Set 2	Coefficients (γ)
AGE	0.0933	TTO	0.0168
OCC	-0.0009	TFRM	-0.0344
CNEC	-0.0000	OTT	0.0184
COWN	-0.0442	OPE	0.2974
INC	0.9500	E/INC	-1.0485
CARA	0.0341	FREQ	0.0200

Significance test: $R_{c_1} = 0.91$; $\chi^2 = 1{,}940.0$; d.f. = 36; $p < 0.001$.

Table 5. Second canonical correlation test of the interdependence between socioeconomic and transportation service characteristics for bus riders.

Variables of Set 1	Coefficients (α)	Variables of Set 2	Coefficients (γ)
AGE	0.0892	TTO	0.0083
OCC	0.0279	TFRM	-0.0662
CNEC	-0.0000	OTT	-0.0998
COWN	-1.8093	OPE	-1.2693
INC	0.3940	E/INC	0.0762
CARA	-2.1340	FREQ	0.9828

Significance test: $R_{c_2} = 0.49$; $\chi^2 = 278.0$; d.f. = 25; $p < 0.001$.

Table 6. Mean total travel time, by income category and mode.

Income Category (dollars)	Mean Travel Time (minutes)	
	By Car	By Bus
<4,000	25.4	41.0
4,000-8,000	30.8	37.5
8,000-12,000	30.8	36.4
>12,000	32.3	38.0

Significance test: Variance ratio[a]

Source of Variation	d.f.	Sum of Squares	Mean Square	F	P
Mode	1	54.50	54.50	2.32	n.s.
Income	3	55.44	18.50	0.79	n.s.
Error	3	70.44	23.50		
Total	7	180.38			

[a]Variance ratio F is the estimate of S^2 based on the variation in travel time by mode ÷ the estimate of S^2 based on the variation in income.

Comparison of Correlation for Mode Groups

Comparison of the two mode groups tells us something about the strength of the relationship between socioeconomic and transportation system factors for each group. First, the sensitivity of bus riders to transportation system characteristics is greater than in the car driver group, as shown by the relative values of the correlation coefficient ($R_{c_{bus}} = 0.91$ and $R_{c_{auto}} = 0.71$). The implication is that bus riders have the type of socioeconomic constraints that make them dependent on the attributes of the transportation system whereas car drivers have more freedom to choose different combinations of service attributes and therefore are less dependent on the attributes of the system. The correlation between the two sets of variables denotes a state in which decisions of car ownership, residential and/or job location, and mode choice are interdependent. The results support the idea that those who drive cars, presumably of a high-car-ownership category, have a better choice of residence and job location than those who are more dependent on transportation services. It also implies that pricing control policies will have a smaller locational effect on this group than on the group who currently use transit. That is, if the disutility of travel becomes unacceptable to this group they may tend to change job or home location to relieve the situation rather than adjust to a controlled change in the existing system.

Second, in both groups, income and system cost factors are the prime components describing the interrelationship of socioeconomic structure and behavior. It is evident, however, that parking charges (OPE for car drivers) have more influence relative to the other system components for the car drivers than fares do for transit passengers (OPE for transit group). Thus, high incomes are associated with high out-of-pocket expenses for both groups, but for transit riders this is more or less fixed, modifying its effect. Income and cost modified by the ability to pay (OPE/INC) shows a high interdependence in both groups.

While the first canonical variate shows interdependence of income and cost, the second canonical variate brings out the positive relationships between the other socioeconomic characteristics and bus frequency. For both groups, car availability and bus frequency are related. This can be explained through the car-ownership factor, since low frequencies would precipitate higher car ownership, which is brought out by a high intercorrelation of car ownership with car availability ($r = -0.91$ for car group and $r = -0.86$ for the bus group).

The analysis supports the idea of a reciprocal relationship between car ownership and bus service. With the high car-ownership rate of the study area, the effect is probably due to the multiple-commuter households of many of the apartments in the area. Thus, the existence of a good bus service would doubtless delay a number of nonfamily households (single people living communally) from the purchase of their first car or the purchase of a second car.

SOCIOECONOMIC STRUCTURE AND MODE SHIFT PROPENSITY

A second series of tests was carried out to determine if the socioeconomic structure of the corridor was likely to have a differential effect on causing automobile drivers to shift mode. A previous study shows that the propensity to shift from automobile commuting is dependent mostly on changes in the frequency of buses and the residential travel time, with secondary influences by overall travel time and parking costs (9). The question is whether these influences can logically be stratified by the socioeconomic profiles of the commuters. If so, the interdependence between the socioeconomic structure of the corridor and the particular system attributes that are important to each socioeconomic group adds a further dimension to be considered in the mode choice.

To eliminate some of the constraints on behavior patterns imposed by the existing system attributes, the tests were based on the stated preferences for an idealized system. The hypothetical system was a park-and-ride combination in the corridor using express buses for corridor line haul. Automobile drivers were asked to indicate the scale position at which they would shift to the system for each of the influences above. After editing, 465 commuters served as the data base for this test.

The ratio of the actual measurement of the system attribute experienced at the time of the trip compared to the measurement indicated on the preference scale was used as the relative measure of the variable. Variables derived, expressed as a ratio of actual system state to preferred state, were as follows:

$$X_1 = \frac{\text{actual overall travel time}}{\text{preferred overall travel time}}$$

$$X_2 = \frac{\text{actual out-of-pocket expenses (parking cost)}}{\text{preferred out-of-pocket expenses (parking cost and transit fare)}}$$

$$X_3 = \frac{\text{actual travel time from home to vehicle}}{\text{preferred transfer time at a park-and-ride terminal}}$$

$$X_4 = \frac{\text{actual frequency of available buses}}{\text{preferred frequency of buses at park-and-ride terminal}}$$

$$X_5 = \frac{\text{parking charge at CBD destination}}{\text{parking charge that would cause a shift to the new mode}}$$

The discrimination-classification statistical analysis was used to determine which of these relative system variables would be important in a mode shift for different socioeconomic characteristics. Discriminant analysis estimates vector coefficients of linear discriminant functions that, when solved, define the position of an individual on a line that best separates predetermined classes or groups (10). The estimated position on the line is a linear function of the travel characteristics of the individual. The original travel characteristics are transformed to discriminant "scores" by the statistical criterion of maximizing the ratio of the square of the differences between the mean of any group and the grand mean to the pooled within-group variance. Assumptions are that the variables are multivariate normal and that group variance-covariance matrices are equal. Classification into groups is accomplished by assignment of individuals to one of the predetermined groups based on the vector solution of the discriminant function for each group. The statistical validity of group assignment is made by posterior classification of the original group members.

Tests were made of each of four socioeconomic categories and discriminant functions used to determine the number of groups into which each category should be divided to achieve the best loading of the variables. This resulted in two age groups, those over 40 years and those under 40 years; two car-ownership groups, single- and multiple-car families; four income groups, very low (< \$4,000 per annum), low (\$4,000 to \$8,000), medium (\$8,000 to \$12,000) and high (> \$12,000); and six categories of occupation, managerial, professional, secretarial, clerical, sales, and other. The discriminant functions in all cases provided significant separation of the groups at $F_p < 0.05$.

Table 7 summarizes the results of the statistical tests. The summary shows the overall importance of the transportation service variables in discriminating between the socioeconomic classes tested. The underlined variable is the most important factor in giving the relative level of service change needed to cause a mode shift. For example, the frequency of bus service is the most important change that must be implemented for commuters of different age categories. In this case the influence of out-of-pocket expenses is also a significant factor.

The posterior classification is a measure of the ability of the linear function of scaled vector weights to assign an individual of unknown class with given relative transportation service preferences to a group category. In this case, although the discriminant functions are statistically significant, their ability to assign class is relatively poor, attesting to the fact that the test does not show conclusive results. The test does, however, point to some tentative conclusions about the interrelationship of socioeconomic characteristics and the tendency to shift mode.

Influence of Age and Car Ownership in Mode Shift

Tables 8 and 9 give the group means on the significant variables for different age and car-ownership categories. The interpretation of the tables is through the means of the relative transportation service variables. The larger the mean value for each variable, the more resistant that group is to shifting mode. This is true because there is a greater difference between the measure of the existing service and that any individual in the group would prefer in those cases where a smaller value of the attribute

Table 7. Statistical summary of interdependence of socioeconomic characteristics with mode shift propensity.

Socioeconomic Characteristic	Scaled Vector Weights for System Variable[a]					Test of Group Separation			Posterior Classification, Percent Misses
	X_1	X_2	X_3	X_4	X_5	Λ^b	F_p^c	Percent of Trace[d]	
Age	5.98	37.67	-0.56	47.46	2.12	0.96	<0.01	100	40.6
Car ownership	9.73	8.92	8.52	-0.52	-2.06	0.97	<0.05	100	46.4
Income	-3.50	104.71	-14.38	12.14	-3.80	0.90	<0.001	63	62.2
Occupation	-3.51	-12.11	11.43	-28.64	7.04	0.91	<0.01	50	79.8

[a]Only the first discriminant function is given.
[b]Wilk's lambda criterion for discriminating power of the function: $\Lambda = |W|/|T|$ or equivalently $\Lambda = \prod_{i=1}^{r} \left[\frac{1}{1+\lambda_i}\right]$, r = number of roots.

[c]$F_p = F_{probability}$ = the chance of producing group differences this large or larger! This test is based on $F = \left(\frac{1-\Lambda}{\Lambda}\right)\left(\frac{N-g}{g-1}\right)$ N = number of observations, g = number of groups.
[d]Percent of trace = the percentage of the total discriminating power of the vector shown.

Table 8. Group means on significant variables for those over 40 years and those under 40 years.

Significant Variable	Group Means	
	U_{40}	O_{40}
X_2(OPE)	3.26	2.07
X_4(FREQ)	4.88	3.91

Table 9. Group means on significant variables for single- and multiple-car families.

Significant Variable	Group Means	
	Single	Multiple
X_1(OTT)	1.11	0.94
X_2(OPE)	3.01	2.30
X_3(TTO)	0.47	0.30

Table 10. Group means on significant variables for very low, low, medium, and high income commuters.

Significant Variable	Group Means			
	VL	L	M	H
X_1(OTT)	1.11	1.07	1.08	0.90
X_2(OPE)	1.31	1.79	3.14	2.94
X_3(TTO)	0.71	0.61	0.29	0.24
X_4(FREQ)	3.58	4.21	4.43	4.54
X_5(PKCHG)	1.04	0.55	0.53	0.62

Table 11. Group means on significant variables for managerial, professional, secretarial, clerical, sales, and other occupation categories.

Significant Variable	Group Means					
	Managers	Professionals	Secretaries	Clerical	Sales	Other
X_1(OTT)	1.01	1.04	1.18	1.11	0.90	0.88
X_2(OPE)	2.28	2.85	1.27	1.04	4.78	4.87
X_3(TTO)	0.35	0.32	0.30	0.52	0.20	0.84
X_4(FREQ)	4.10	4.79	4.18	4.02	5.24	3.64
X_5(PKCHG)	0.62	0.52	0.97	0.41	0.66	0.76

is logically preferred, that is, variables X_1 to X_4. For the variable measuring the parking charge required to shift, X_5, the opposite rule applies: The lower the mean value the more resistance to shift mode with a given service value.

The results for the different age groups indicate that those under 40 years are more reluctant to shift mode than those over 40, considering changed service levels for bus frequency and out-of-pocket costs. Since the ratio of actual to preferred frequency is about 5:1 for those under 40 and 4:1 for those over 40, if the existing frequency was 1 bus every 20 minutes the under-40 group would require that it be decreased to a 4-minute frequency before shifting mode while the over-40 group would shift with a 5-minute frequency. A greater decrease in out-of-pocket cost would also be demanded by the younger group.

Similar results for car ownership implies that those of single-car families would be more resistant to shift than those of multiple-car families.

These results are not in the direction expected, which was that reluctance to shift mode would increase with age and car ownership. There appears to be no good explanation for the apparently odd results here except that the statistical tests extracted a very low percentage of variation in the data, indicating that further tests on a different sample may show more conclusive results.

Influence of Income in Mode Shift

The best association was between income categories and mode shift tendencies (Table 10). The results show that as income increases the resistance to a mode shift increases, as shown primarily through the service variable of cost and frequency. The higher income groups are less sensitive to cost than the middle range, a result we would expect. It is also evident that an increase in income creates more tolerance to travel time variables (OTT and TTO), a result consistent with the finding of the previous section. It appears that the variation across either the income groups or the travel times is not great enough to produce the suspected relationship between incomes and travel time. The conclusion from the results here is that some increase in walking times would be acceptable providing that bus frequencies were substantially increased (i.e., by 300 to 400 percent).

The tests also imply that as income increases the charge for parking necessary to cause a mode shift also increases, except again for the highest income group. The very-low-income group is very sensitive to parking charge increases, indicating that any increase whatever would cause them to shift mode.

Influence of Occupation and Mode Shift

Occupation does not appear to have much influence on the propensity to shift mode. Table 11 indicates some tendency for managers and professional employees to be sensitive to out-of-pocket expenses. However, this does not appear to be intuitively reasonable and bears further investigation. Sales people and craftsmen on the other hand are shown to be sensitive to cost factors, as expected. Managers, professional workers, and sales people are prepared to walk some distances while craftsmen and laborers are not. Secretaries are the most sensitive to parking fee increases, while clerks are least sensitive. Laborers, sales people, and managers are above average in sensitivity to parking fee increases.

CONCLUSIONS

Correlation tests show an interdependency between level of income and travel expenses when the correlation between socioeconomic structure and system attributes is maximized. Those of higher incomes have an ability to select the more expensive alternative. This is as expected and has been seen in the increased ownership and use of automobiles as the general level of affluence has increased. Also of interest are the interdependencies of other structural variates with system performance. Car ownership and availability are related to excess travel times and the frequency of bus service. This follows intuitive reasoning and can be seen in current transit planning. The decision to extend bus lines into new areas usually follows development of these areas when there is a sufficient perceived demand to justify the extensions. If car ownership is high, demand for bus service is low, and therefore service is only provided when those who have no transportation choice become a significant group to warrant it. On the other hand, where transit service is already adequate, the need for a second or third car diminishes. The inference is that, if a high-quality transit service is provided to a developing area, the demand for such a service would cause a switch away from multicar ownership. This, however, would require a change in the "pay as you go" philosophy of transit decision-making and would require subsidization of capital and operating expenses until demand increased to economic levels.

One finding of the study is that socioeconomic characteristics of commuters exert some influence on sensitiveness to shift mode. In general, those under 40, from families with one car, with middle to higher incomes, in the nonprofessional occupations, would be more resistant to shift than the population as a whole. The age factor may influence mode shift propensity through out-of-pocket expenses and frequency of service. Car ownership is a potential factor because of overall travel time and residential walking time. There is probably a spatial effect here as well, since car ownership no doubt increases as distance from the CBD increases, thereby pointing up the trade-off between travel time and owning another car. Income influences are varied. The lower income groups are more time-sensitive than the higher income groups, although the latter groups are more sensitive to transit frequencies and out-of-pocket costs. On the other hand, lower income groups would tolerate less walking than the higher income groups and are more sensitive to parking charge increases.

The findings of this investigation are still tentative, but they do point to possible interrelationships between socioeconomic characteristics of a transportation corridor and the transportation service attributes serving the corridor. Further research is necessary using a data base collected for the purpose of examining some of the hypotheses expressed here in which both the range and extent of socioeconomic and transportation variables can be enlarged.

ACKNOWLEDGMENT

This research was carried out under a grant from the National Research Council of Canada.

REFERENCES

1. Fertal, M. J., et al. Modal Split: Documentation of Nine Methods for Estimating Transit Usage. U.S. Bureau of Public Roads, 1966.
2. McGillivray, R. G. Demand and Choice Models of Modal Split. Jour. of Transport Economics and Policy, May 1970.
3. Kraft, G., and Woho, M. New Directions for Passenger Demand Analysis and Forecasting. Transportation Research, Vol. 1, No. 3, 1967.
4. Domencich, T. A., Kraft, G., and Valette, J. P. Estimation of Urban Passenger Travel Behavior: An Economic Demand Model. Highway Research Record 238, 1968, pp. 64-78.
5. Brand, D. Theory and Method in Land Use and Travel Forecasting. Highway Research Record 422, 1973, pp. 10-20.
6. Manheim, M. L. Practical Implications of Some Fundamental Properties of Travel-Demand Models. Highway Research Record 422, 1973, pp. 21-38.
7. Anderson, T. W. An Introduction to Multivariate Statistical Analysis. John Wiley, New York, 1958.
8. Zupan, J. M. Mode Choice: Implications for Planning. Highway Research Record 251, 1968, pp. 6-25.
9. Brown, G. R. Analysis of User Preferences for System Characteristics to Cause a Modal Shift. Highway Research Record 417, 1973, pp. 25-36.
10. Cooley, W. W., and Lohnes, P. R. Multivariate Procedures for the Behavioral Sciences. John Wiley, New York, 1962.

APPENDIX

VARIABLES USED IN ANALYSIS

The variables selected for analysis were those collected in a survey on one bridge approach to the CBD of Vancouver, Canada. The survey was a hand-out-mail-back questionnaire that both car drivers and bus passengers were asked to fill out and return. The data matrix consisted of 1,244 car drivers and 967 bus passengers, after editing to remove car passengers, zero entries, and captive bus passengers. The variables used in the analysis were as follows.

1. Age. The age category of each respondent was coded between 1 and 4, designating 0-20, 21-40, 41-60, and over 60 years.
2. Occupation. The occupational categories in the survey were reorganized in a new hierarchy in accordance with Blishen's socioeconomic index for occupations. Blishen devised an interval-scaled index of occupations in Canada. The occupation variables in the multivariate analysis were rank-ordered according to Blishen's hierarchy. A code number between 1 and 6 was assigned to the six categories of the work-purpose trip in accordance with the rank of that occupation.
3. Car Necessary for Work. The question, "How often is it absolutely necessary to use your car during the day?" was coded from 1 to 4 to designate "never", "very seldom", "once a week" or "frequently". All bus passengers were coded "1".
4. Car Ownership. This variable was coded 1 to 4 designating none, one, two, and three or more cars in the household. Since the analysis is for "choice" trips, only those households that reported owning one or more cars were included in the data matrix.
5. Income. Income was coded 1 to 4 designating under \$4,000, \$4,000 to \$8,000, \$8,000 to \$12,000, and over \$12,000 categories.
6. Car Availability. Since household ownership of an automobile may not reflect the actual availability of a car for a given trip, a proxy based on the estimated availability of a car and the competition among members of the household for car use was included. This variable accounts for different levels of car ownership, persons per household (zonal average), and income:

$$\text{Car availability} = \frac{\text{Persons per household} \times \log \text{income}}{\text{Cars per household}}$$

This proxy variable defines the competition between members of the household in terms of the number of persons in the household and the number of cars owned, modified by the demand for travel. If the car was purchased for commuting only, the availability of a car for commuting is a simple relationship between the number of commuters and the number of cars owned. If there were one car per commuter there would be no competition for the use of the car, and the mode choice would be related to factors other than car ownership. Intuitively, the use of transit would increase as this simple ratio decreased from the value of one. However, the number of persons and cars owned per household for commuting must be related to competition from other purpose trips as well, such as shopping and social-recreation trips carried out by noncommuting members of the family. The income factor takes this into account. As income per person increases, the number of trips demanded increases. But there is a limit to the number of trips and there are also possible economies of scale. Therefore it is postulated that the desire for individual travel is related to income, but at a decreasing rate, and the log of income becomes the proper modifier for car availability. Income is the reported individual income, and persons per household is the average number of persons per household in each zone. Persons per household is taken from the 1966 population census tracts and converted to the survey zones. Cars per household is that reported by survey respondents.

7. Residential Travel Time. This variable measures the length of time to travel from the start of the work journey to the bus stop or to a car. Although the original survey times were categorized (0 minutes, 1-3 minutes, 3-5 minutes, 5-10 minutes, and

10 or more minutes), the intervals were unequal and a significant number of responses were in the open-ended category (10 or more minutes), and thus it was decided to treat this variable as an ordinal scaled response. Therefore the categories were coded from 1 to 5 inclusive.

8. CBD Travel Time. This variable is the walking time from the parking location or bus stop to final destination. It was also ordinalized in the same way as residential travel time, since all conditions were parallel.

9. Overall Travel Time. This measures door-to-door travel time for both auto and bus passengers in 5-minute increments. These increments are probably the minimum that can be perceived by users. That is, perceived and reported times are given to the nearest 5 minutes, and any finer breakdown is probably meaningless in terms of subjective responses.

10. Parking Charge. Parking charges levied are the manifestation of out-of-pocket expenses for automobile drivers, as are fares for transit riders. Most commuters pay parking fees by the month. Reported monthly fees were converted to daily rates to be compatible with the other components of daily travel. On the assumption there are 20.8 working days per month, less 10 statutory holidays per year (or 0.8 per month), the reported monthly rate is equivalent to the reported daily rate if divided by 20 (20.8 - 0.8). Occasionally researchers split parking fees, with half of the fee assigned to the journey to work and half to the journey from work. It was reasoned here, however, that the perceived parking charge would be the total charge per day, since this would be the manner in which the transfer of money would take place. This is particularly true of subscribers, who it is postulated would not attempt to cost a single trip.

11. Fare. Both transit agencies reported that most fares are in fact commuted fares, but no precise breakdown is available. Therefore it was assumed that all commuters would take advantage of commuted fares where available. The one-way fares were then doubled to conform with the nature of the perception of parking charges.

12. Parking Charge/Income. This variable is a proxy incorporating parking charge divided by income, on the premise that the parking rate as an influence in mode choice would be more meaningful if related to income.

13. Frequency. This was taken as the average frequency over the period between 7 and 9 a.m. Since the minimum difference in average frequency for commuters is 5 minutes, and since the original survey did not report exact frequencies facing individual travelers, it was decided that average frequency for each zone would adequately describe the perceived dimension of transit frequency.

The variables are measured in different scales of time, space, and dollar units. The score matrices were standardized and adjusted by Sheppard's correction factor by dividing each row score by the corrected standard deviation of the variate. Standardization, in which the mean of the variate over the population is zero and the standard deviation equal to unity, was necessary in some tests to reduce both sets of variates (the socioeconomic ones and the behavior ones) to the same metric. Standardization of the variates has no effect on the results of the analysis.

GROUND TRANSPORTATION PLANNING IMPLICATIONS OF AIRLINE SHUTTLE PASSENGERS

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The authors have researched ground transportation characteristics of passengers using the Air-Shuttle services provided at LaGuardia Airport by Eastern Airlines, Inc. The research establishes relationships between characteristics of shuttle passengers, comprising about 15 percent of all LaGuardia enplanements, and the other passengers using LaGuardia Airport and Eastern Airlines facilities. Because of the importance business travelers place on convenient scheduled service with minimum interruption from checking into and out of the system, it is anticipated that shuttle-type airline service concepts will emerge in the more heavily traveled air corridors in the future. Data from field surveys have been analyzed relative to the impacts that shuttle travelers at LaGuardia have on the road system, parking facilities, and curb frontages at terminal buildings. Results indicate that shuttle passengers have parking durations about 50 percent less than other terminal passengers and that their parking space demands are about 40 percent less than other system passengers. Other details as to arrival modes, parking durations, vehicle occupancy, duration of parking at curb frontages, and a profile of the shuttle passenger are given.

•PHENOMENAL increases in air travel have been experienced in the last 2 decades. This has revolutionized life styles and business practices by bringing together peoples of all nations and regions. It has further impacted land development and ground transportation travel patterns in many of our greater cities.

For a trip between 100 and 150 miles in length, modal choice is almost academic in that terminal times between origin and destination with automobile, bus, conventional rail, or air are comparable, depending on the trip. As travel distances increase beyond 150 miles, the air trip gains in popularity because of the time savings and the usual convenience experienced in selecting this mode.

Using this premise as a basis for further study of air travelers, one can recognize the important contribution that innovations have made to the treatment of passengers and visitors to airport terminals today. Among those that have been inaugurated in the recent past are computerized reservation systems, pre-ticketing concepts, and scheduled-sustained shuttle service between major airport hubs.

It has recently been determined, for example, that more than 90 percent of the enplaning passengers departing New York via JFK International Airport are pre-ticketed. This high number signifies the importance of minimizing delays and inconvenience.

The growth trend in U.S. air patronage is shown in Table 1. As indicated, the growth from 1963 has been relatively strong, with only the period between 1969 and 1971 showing a lesser rate. Forecasts for 1982 are for continued strong annual growth, increasing at a rate of almost 10 percent per year. These forecasts, however, do not reflect the energy crisis and its implications on less air travel.

THE SHUTTLE CONCEPT

Recognizing the attraction between major city pairs, Eastern Airlines inaugurated the Air-Shuttle service from LaGuardia Airport to Washington's National Airport and from

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

Table 1. Air passenger traffic growth trends, scheduled carriers.

Fiscal Year	Total Passenger Enplanements: Millions of Passengers	Total Passenger Enplanements: Percent Increase
1963	70.7	—
1964	83.0	17.4
1965	94.6	14.0
1966	113.9	20.4
1967	126.4	11.0
1968	152.6	20.7
1969	168.0	10.1
1970	171.4	2.1
1971	170.0	-0.8
1972	182.9	7.6
1977[a]	286.5	56.6
1982[a]	442.0	54.3

Source: Ref. 1.

[a]Passenger forecast by FAA.

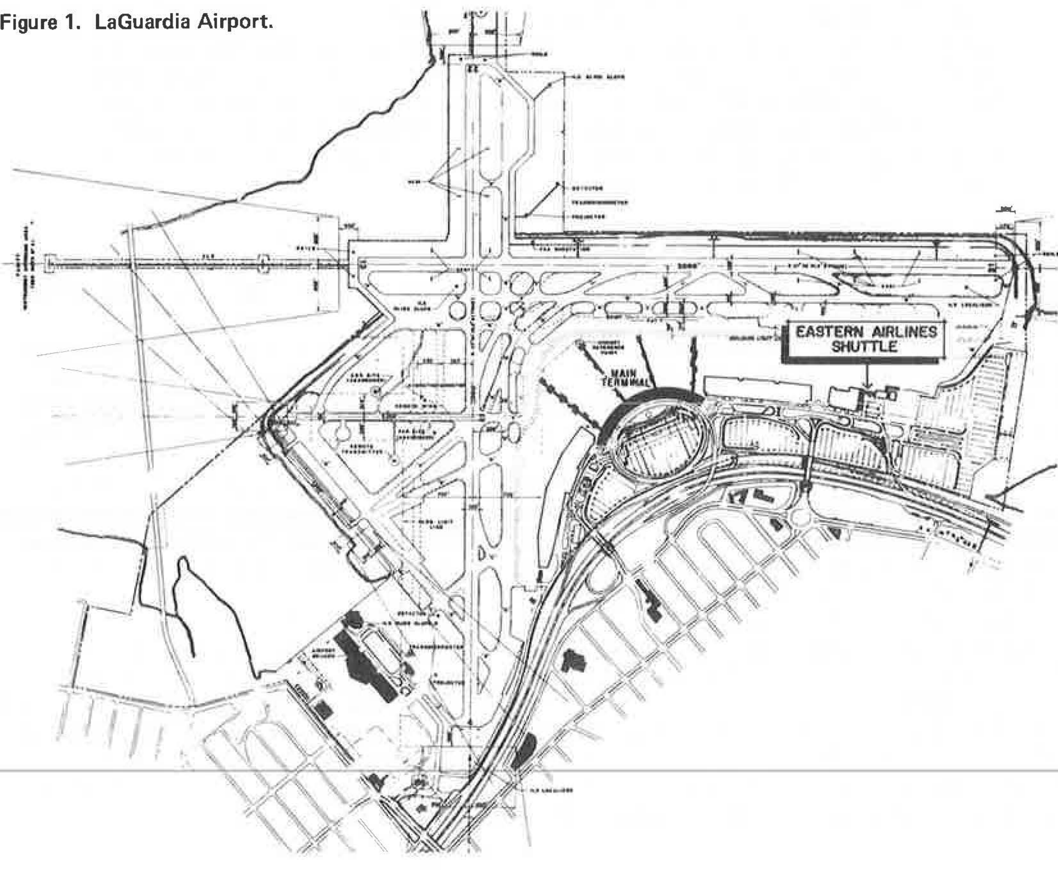
Table 2. Air-Shuttle traffic growth at LaGuardia.

Year	Annual Shuttle Passengers[a]: Enplanements	Annual Shuttle Passengers[a]: Deplanements
1961[b]	250,559	239,633
1962	532,129	511,477
1963	835,801	826,557
1964	922,448	912,171
1965	950,956	946,513
1966	979,874	979,045
1967	1,139,387	1,118,300
1968	1,085,713	1,045,875
1969	1,142,452	1,112,312
1970	1,064,155	1,054,326
1971	974,319	949,336
1972	1,009,354	989,296

Source: Eastern Airlines.

[a]Passengers from LaGuardia Airport to Boston and Washington and return.
[b]Statistics from May 1961.

Figure 1. LaGuardia Airport.



LaGuardia to Logan International Airport in Boston in 1961. [Air-Shuttle is a trademark for service by Eastern Airlines, Inc.] The service was in response to marketing analyses of the traveler who desires scheduled and frequent service without fanfare and with minimum interruption in the terminal. All passengers are guaranteed a seat, assuming they arrive at the gate by departure time, which is scheduled on the hour, daily, between 7:00 a.m. and 10:00 p.m. between New York and Washington, New York and Boston, and vice versa. Tickets are issued in flight, and all baggage is loaded on the plane at the time passengers board. In the event the first section fills, it is dispatched to the destination city and a second plane is placed into service. Should other sections be required, the carrier will furnish them.

The concept has been expanded now to Montreal and from Newark to Washington and Boston on a 2-hour frequency daily. The hours of operation to Montreal are from 7:30 a.m. to 9:30 p.m., and other cities are being considered for this service. [As a result of the energy crisis, Eastern Airlines has announced a reduction in shuttle services between New York and Montreal and flights from Newark Airport.]

American Airlines and United Air Lines offer similar but less frequent service to Washington and to Chicago from New York. Reservations are required in advance and ticketing at the gates is according to conventional practice.

Eastern's experience in public acceptance of the shuttle service has been quite favorable, as indicated by annual LaGuardia Airport patronage figures in Table 2. Since the service was inaugurated between New York and Washington and Boston, there has been an increase of almost 400 percent in annual patronage.

The concept, with variations, is being employed in other heavily traveled corridors on the West Coast and in the Midwest, and further studies are being made by industry to initiate similar service on the East Coast.

PROFILE OF SHUTTLE PASSENGERS

A study was made of ground transportation characteristics of Eastern Airlines shuttle passengers and Eastern Airlines main terminal passengers at LaGuardia (Fig. 1) for purposes of assessing ground transportation requirements and parking demands for an expanded terminal complex. Surveys were conducted during February and June 1973.

Eastern Airlines shuttle patronage totals 15 percent of all enplaning passengers at LaGuardia and represents 55 percent of all Eastern Airlines passengers being served at the airport. Some characteristics of shuttle passengers are as follows:

1. Business-oriented trips account for 65 percent of all shuttle users;
2. Passengers arrive by the quickest and most convenient means of transportation;
3. Over 20 percent of patrons fly twice a month;
4. Passengers create least impact on traffic of all passenger arrivals;
5. Minimal time is spent in the terminal building and at curb frontages by passengers;
6. Short-duration trips prevail, with over 55 percent of originating passengers returning the same day;
7. Least number of bags are carried, averaging 1.5 per person (predominantly carry-on brief cases); and
8. Average parking duration is approximately half of non-shuttle users (17 hours versus 37 hours).

In general, the shuttle passenger does not want to be hampered by schedules, desires service and frequency, and is the least burden on the carriers.

MODE OF ARRIVAL AT LAGUARDIA AND OTHER AIRPORTS

In the design of ground access/egress facilities, it is important to know passenger arrival patterns. Figure 2 shows that LaGuardia shuttle and system passengers make similar modal choices daily. Taxis comprise the primary mode, accounting for 42 percent of shuttle patrons and 46 percent of the total system passengers. The second most popular mode of arrival is the private automobile. Shuttle passenger use of the automobile is slightly higher (41 percent) than system passengers (38 percent). Bus and limousine modes are equal for both groups and represent about 16 percent.

Figure 2. Comparison of daily passenger arrivals by mode.

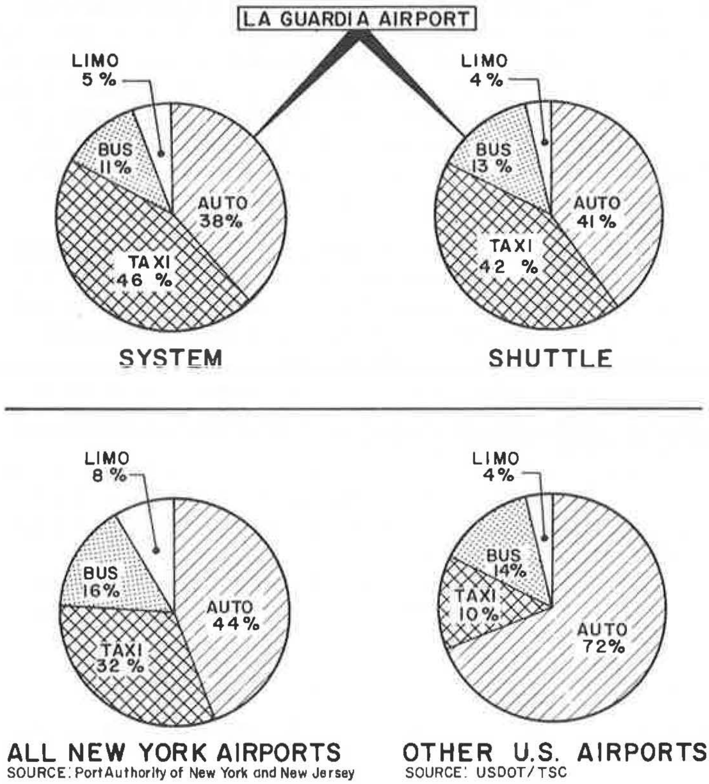
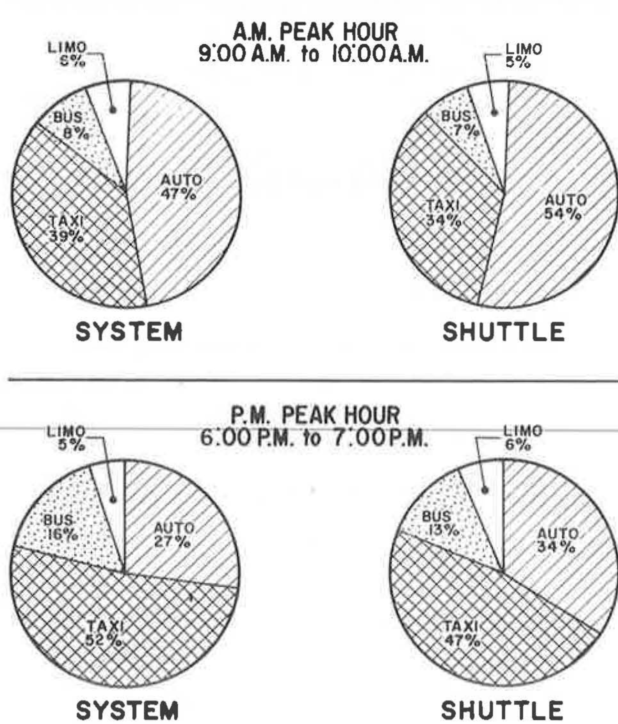


Figure 3. Comparison of peak-hour passenger arrivals by mode.



These proportions are representative of all New York airports. As shown in Figure 2, 44 percent of all passengers arrive by automobile and 32 percent by taxi. This differs from national trends, where 72 percent of all passengers arrive by automobile and 10 percent use taxis. The remaining 18 percent use transit or commercial vehicles.

PEAK-HOUR ARRIVAL AND DEPARTURE MODES

Peak-hour arrival modes, shown in Figure 3, reveal differences contrasted with daily figures. The peak hours are based on peak arrival times of enplaning passengers at the airport. In the morning peak hour, 9:00 a.m. to 10:00 a.m., 54 percent of all shuttle passengers arrive by automobile and 34 percent by taxi. The remaining 12 percent make use of buses and limousines. Corresponding values for system passengers are 47 percent auto and 39 percent taxi.

Comparing these values to those of deplaning passengers, shown in Figure 4, indicates a lesser use of the automibile. Approximately 17 percent of the shuttle passengers make use of an automobile, supporting the heavy reliance on the taxi (59 percent) by businessmen destined for Manhattan and other central business districts. These are people from Boston or Washington on trips to the New York area.

Similarly, in the evening, an increase in the percentage of taxis related to enplaning shuttle passengers reflects the return of the businessmen to the airport. In this instance, 47 percent of the shuttle passengers and 52 percent of the system passengers select taxi as the mode for the trip to the airport.

As would be expected, automobile use for deplaning passengers increases in the peak evening hour (6:00 to 7:00 p.m.) and taxi use decreases. As shown in Figure 4, 48 and 53 percent for shuttle and system passengers respectively use automobiles when returning to New York after a day's work in other cities. Buses and limousines receive minimal use for deplaning passengers in the evening peak hour, comprising only 11 percent.

CURB USE CHARACTERISTICS

One of the most critical and noticeable areas of traffic congestion occurs at the curb frontage of the terminal buildings. In planning for curb frontage, characteristics of vehicle occupancy and durations of vehicles parked at the curbs are important considerations.

Vehicle occupancy ratios of shuttle passengers are almost identical to system passengers, as given in Table 3. Approximately 1.5 passengers per automobile (excluding drivers) were found at the curbs for both shuttle and system passengers daily. Occupancy rates for system passengers are identical for both taxi and automobile use at the enplaning and deplaning curbs. Shuttle passenger occupancy for the taxi is somewhat lower, with 1.2 and 1.3 passengers per vehicle for enplaning and deplaning curbs respectively.

Short trips, characterized by few bags, result in shorter durations of shuttle passenger vehicles at the enplaning and deplaning curbs. As indicated in Table 4, at the enplaning curb frontage, duration times for the automobile average 2 minutes less for shuttle passengers than for system passengers. Similarly, buses and limousines also take less time at the enplaning curb. The duration of taxi loading and unloading passengers remains relatively stable for both shuttle and system passengers, averaging approximately 1.5 minutes per vehicle.

Similar comparison of values is found at the deplaning curb, where in all instances a shuttle passenger requires less time than a system passenger. For taxis, the average time at the deplaning curb for a shuttle passenger is 1 minute, as contrasted with 3 minutes for system passengers. The same durations were found for automobiles. Buses exhibited the highest stopping duration of all—6 minutes for system passengers, including time consumed in boarding and alighting and sorting out baggage.

PARKER CHARACTERISTICS

Trip lengths do not necessarily reveal durations of parkers. At LaGuardia, a typical trip length for the average airport user is approximately 2.5 days. This does not compare with the average parking durations found in the parking lots. System passengers

Figure 4. Comparison of peak-hour passenger departures by mode.

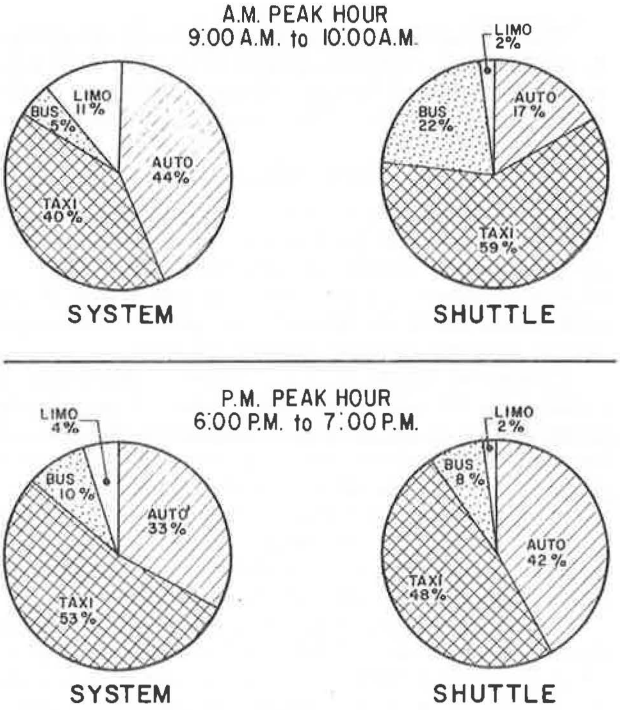


Table 3. Vehicle occupancy at the curb frontage.

Mode	Vehicle Occupancy[a] Enplaning Shuttle	Enplaning System[b]	Deplaning Shuttle	Deplaning System[b]
Automobile	1.3	1.5	1.5	1.5
Taxi	1.2	1.5	1.3	1.5
Bus	3.5	8.0	5.5	7.0
Limousine	1.6	4.0	1.7	5.0

[a]Persons in vehicle excluding driver.
[b]All airlines located in main terminal building.

Table 4. Duration of vehicles at the curb frontage.

Mode	Duration of Vehicles Parking at Enplaning and Deplaning Curbs (minutes) Enplaning Shuttle	Enplaning System[a]	Deplaning Shuttle	Deplaning System[a]
Automobile	1.0	3.0	1.0	3.0
Taxi	1.5	1.5	1.0	3.0
Bus	1.5	3.5	1.5	6.0
Limousine	1.0	2.0	1.0	2.0

[a]All airlines located in the main terminal building.

Table 5. Duration of air passenger parkers.

Duration Parked (hours)	Type of Passenger Shuttle Number	Shuttle Percent	System[a] Number	System[a] Percent
0 to 12	230	63.7	345	27.8
12 to 24	58	16.1	225	18.1
24 to 36	33	9.1	207	16.6
36 to 48	13	3.6	97	7.8
48 to 60	12	3.3	139	11.1
60 to 72	7	1.9	47	3.8
72 to 84	3	0.8	55	4.5
84 to 96	2	0.6	36	2.9
96 to 120	1	0.3	50	4.0
120 to 144	1	0.3	22	1.8
Over 144	1	0.3	20	1.6
Total	361	100.0	1,243	100.0
Average duration (hours)	17		37	

[a]All airlines located in the main terminal building.

average 37 hours parked (1.6 days), as given in Table 5. The difference in duration parked from duration of trips by air can be attributed to the parking cost for more than 24 hours. When the convenience cost of using the automobile appreciably exceeds the passengers' desired cost, another means of transportation will likely be selected.

The shuttle passenger average parking duration of 17 hours is less than half of that of the system passenger.

Another aspect of parking duration depends on the time the vehicle is parked. Figure 5 shows duration patterns of shuttle passenger parkers. As depicted, of those persons who park after 4:00 p.m., 50 percent remain for at least 24 hours. Of those who park before 10:00 a.m. and between 10:00 a.m. and 4:00 p.m., 50 percent stay for less than 10 hours.

Similar analyses have been made for system passenger parkers as shown in Figure 6. In this instance, duration of time parked is much longer. For those parkers who park after 4:00 p.m., 50 percent park less than 54 hours, as compared with 24 hours for the shuttle patrons. For those who park before 10:00 a.m., 50 percent stay less than 13 hours, and, for midday parkers, 50 percent park less than 29 hours.

Other data indicate that, of all passengers arriving by automobile, 53 percent utilize the enplaning curb and 47 percent the deplaning curb. The remaining passengers go directly to parking without stopping at the curb. Also, of all passengers parking, 55 percent park for the duration of their flight and 45 percent are driven to the airport.

LOCATION OF PARKING

Figures 7 and 8 show that parkers always prefer a space most convenient to their destination. Of those destined for the shuttle, 97 percent park in Lots 4 and 5. The majority of parkers destined for the main terminal building park in Lots 1, 2, and 3 and account for almost 82 percent of all parkers destined for this terminal.

CURB FRONTAGE DEMAND

The amount of curb frontage at a terminal directly affects the convenience of arriving and departing passengers and is a major contributor to congestion on terminal roadways. It is particularly critical to the overall trip because this area is the major interface between passengers and their vehicles.

An analysis of curb frontage requirements for the two passenger types (shuttle and system) was performed. Existing conditions indicate that the greatest impact at the curbs would occur during the evening peak hour. At the enplaning curb, 53 percent of the passengers arriving by automobile will utilize the curb, as compared with 47 percent at the deplaning curb. If it is assumed that 500 shuttle and system passengers will arrive and depart, the number of vehicles expected at the curb during the peak hour is determined as given in Table 6. Involved is the application of percent modal splits for arriving and departing passengers and vehicle occupancy factors to the total number of passengers. The total number of spaces for each mode is determined by applying these values to the duration of vehicles parked at the curb.

The results indicate that, during the evening peak hour, system passengers require a total of 720 linear feet at enplaning and deplaning curbs. This compares with 540 linear feet for shuttle passengers, which represents a reduction of 25 percent in curb frontage requirements. Similar results were found throughout the day.

PARKING DEMAND RELATIONSHIPS

Parking demands at airports fluctuate according to the type of facility. Airports such as Chicago's O'Hare and Atlanta, with many interline transfers, have fewer unit space demands for enplaning passengers than Washington's National or LaGuardia. As many as 50 percent of the total passenger movements through O'Hare never use the ground transportation system.

Some years back the Federal Aviation Administration established approximate ratios of unit parking demands as related to enplaning passengers varying between 900 and 1,200 spaces of parking to be provided for each million annual enplaning passengers. This converts to about one parking space per thousand annual enplaning passengers. The

Figure 5. Parking duration patterns of shuttle passengers.

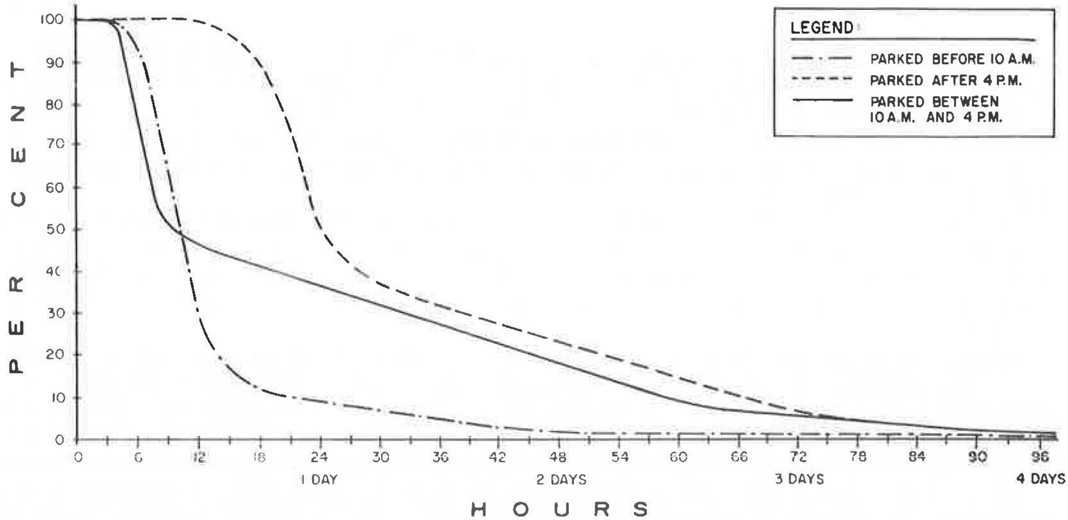


Figure 6. Parking duration patterns of system passengers.

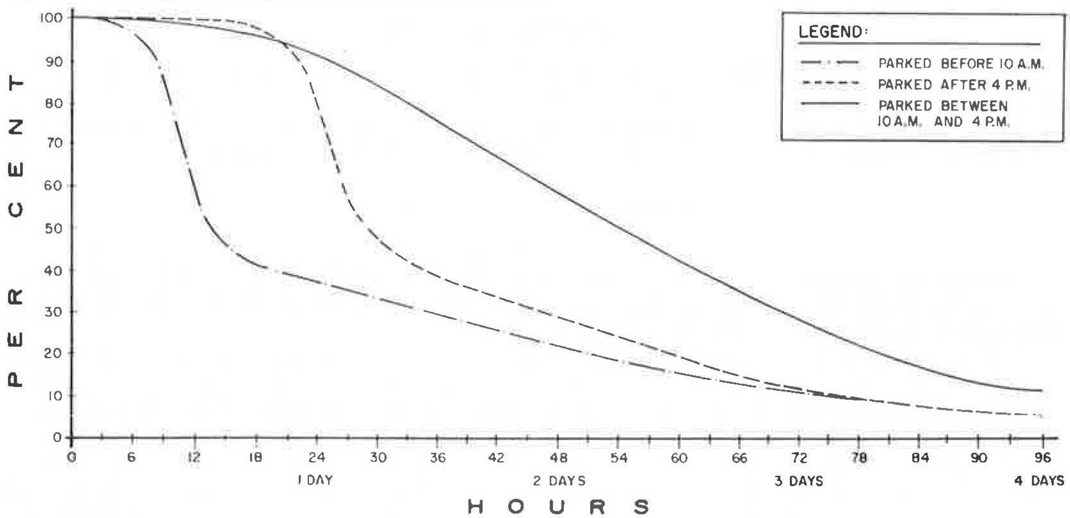


Figure 7. Location of parkers destined to shuttle terminal.

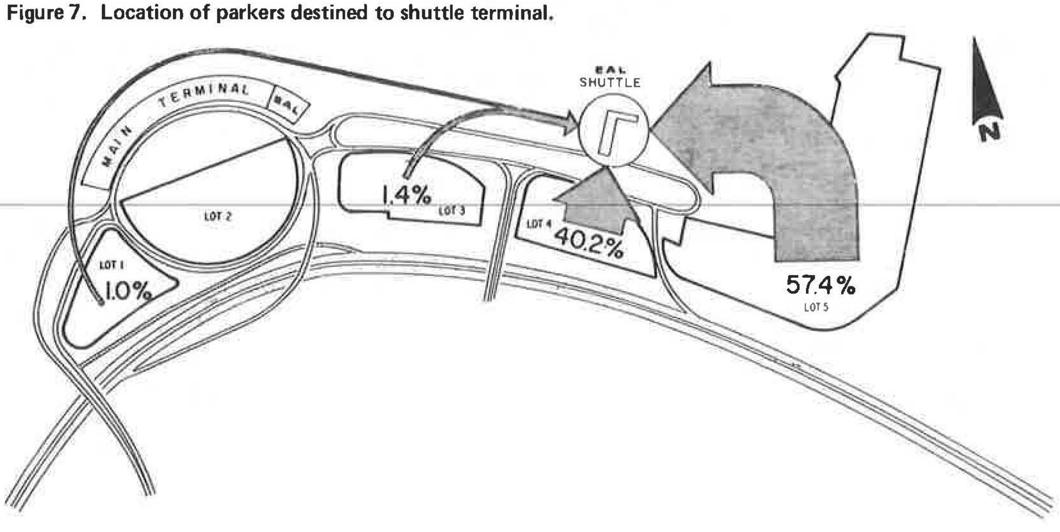


Figure 8. Location of parkers destined to main terminal.

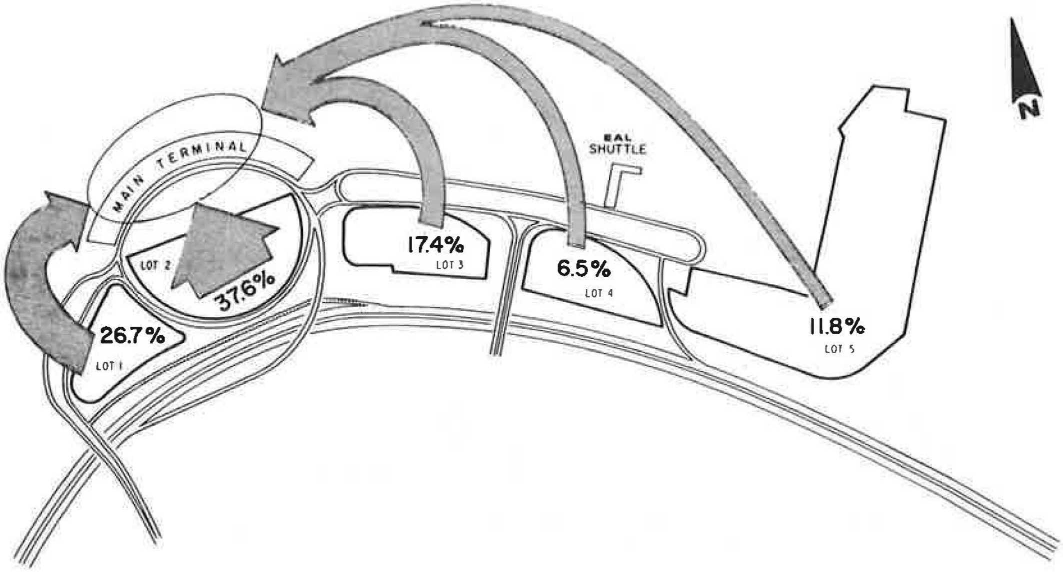


Table 6. Comparison of evening peak-hour curb frontage demands.

Type of Vehicle	Number of Vehicles Using Curb		Duration of Vehicles at Curb (minutes)		Number of Required Spaces		Length of Spaces (feet)[a]	Total Lineal Feet of Curb Required	
	Enplaning	Deplaning	Enplaning	Deplaning	Enplaning	Deplaning		Enplaning	Deplaning
Automobile									
System	50	60	3.0	3.0	3	3	30	90	90
Shuttle	(70)	(75)	(1.0)	(1.0)	(2)	(2)		(60)	(60)
Taxi									
System	175	175	1.5	3.0	5	9	24	120	216
Shuttle	(195)	(185)	(1.5)	(1.0)	5	(4)		(120)	(96)
Bus									
System	10	8	3.5	6.0	1	1	60	60	60
Shuttle	(19)	(8)	(1.5)	(1.5)	1	1		(60)	(60)
Limousine									
System	7	4	2.0	2.0	1	1	42	42	42
Shuttle	(19)	(6)	(1.0)	(1.0)	1	1		(42)	(42)
Total								312 (282)	408 (258)
Combined total								720 (540)	

[a]Includes an allowance for inefficiency in curb use.

Figure 9. Accumulation of parkers.

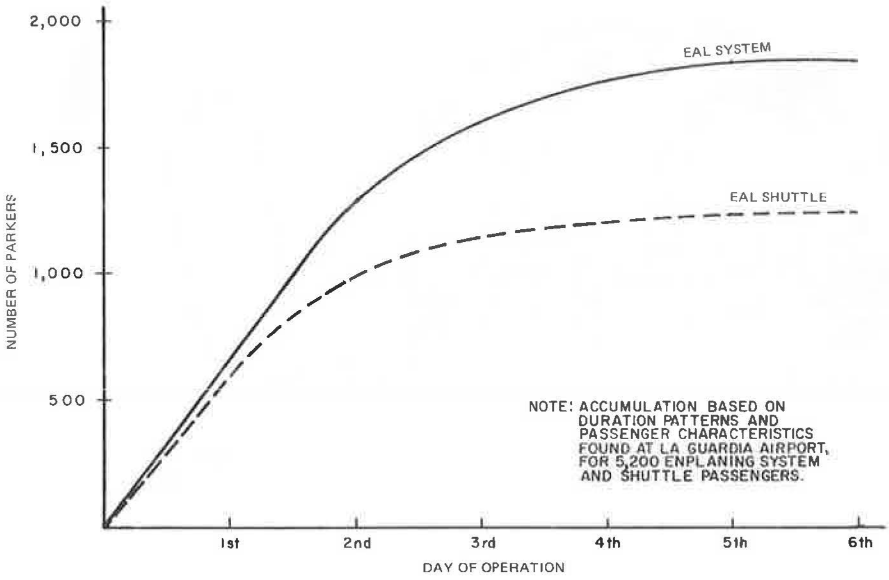
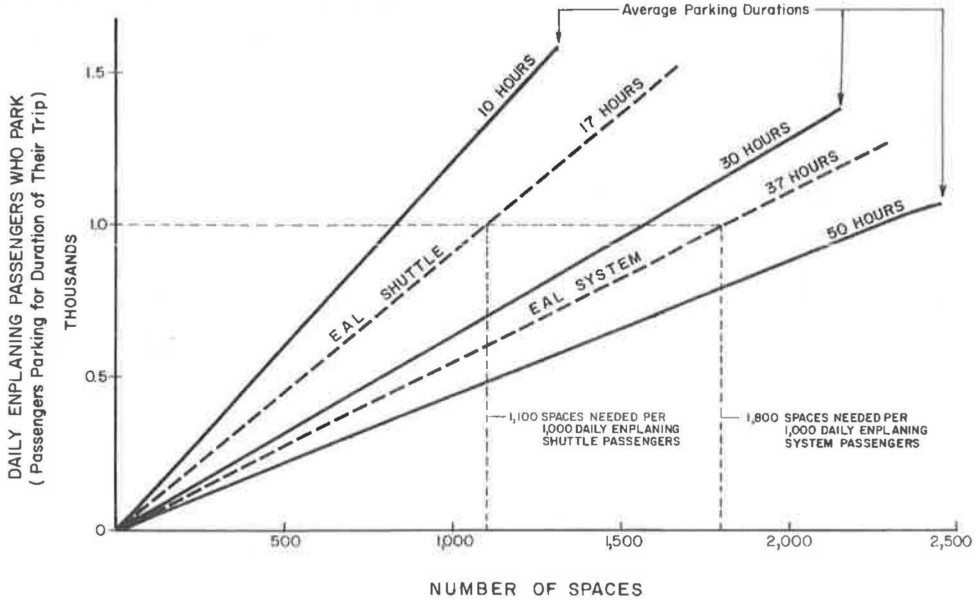


Figure 10. Parking space requirements for passengers.



type of airport and the type of user may alter this figure substantially, which accentuates the importance of studying each individual airport and using rules of thumb for guideline planning purposes.

In computing the parking space demands, a vehicle accumulation matrix was developed in which the number of vehicles parked (and remaining) after each successive day was plotted.

Of 5,200 daily enplaning system passengers, 38 percent, or 2,000 persons, will arrive by automobile, resulting in 1,275 arriving vehicles. Of these, 50 percent, or 635 vehicles, will be parked and left at the airport for the duration of the trip. Similarly, of 5,200 daily enplaning shuttle passengers, 700 automobiles will be parked for the duration of their trip. Using duration factors for parking passengers extrapolated from Figures 5 and 6, peak vehicle accumulation occurs after the fifth day and remains stable thereafter, as shown in Figure 9.

As noted, shuttle passenger parkers require 40 percent less spaces than do system passengers. On a unit basis, for 1,000 enplaning passengers who park for the duration of their trip, 1,100 parking spaces are required for the shuttle passenger, with an average duration of 17 hours. System passenger parkers, however, will require 1,800 parking spaces with an average duration of 37 hours, as shown in Figure 10.

The FAA parking guidelines suggest provision of 300 to 400 spaces per 1,000 daily enplanements. On this basis, 5,200 enplaning system passengers would require 1,600 to 2,100 spaces. The requirement of 1,800 system spaces falls within this range, indicating that the system conforms with existing trends.

CONCLUSIONS

It can be concluded that the shuttle concept, where feasible from a market point of view, is a positive and efficient innovation in serving air travel needs in heavy travel corridors. The user of the shuttle service is usually a repeat passenger who knows the highway system and the functions of the airport and airline and therefore has less negative impact on ground transportation facilities than other air passengers. More enplaning shuttle passengers use private modes and park for durations substantially less than the average system travelers, thereby imposing fewer demands on terminal curb frontages and parking facilities—up to 40 percent less than the system users. Every effort should be given to implementing this concept at other areas in the United States and abroad where markets warrant.

REFERENCES

1. Aviation Forecasts, Fiscal Years 1973-1984. Federal Aviation Administration, Sept. 1972.
2. Ground Access and Parking Requirements, Proposed Eastern Airlines Terminal, LaGuardia Airport. Wilbur Smith and Associates, 1973.
3. Inflight Shuttle Passenger Survey, LaGuardia Airport. Eastern Airlines, Inc., June 1973.
4. Inflight Passenger Surveys, LaGuardia Airport, 1968 and 1972. Port Authority of New York and New Jersey.
5. Port Authority of New York and New Jersey, miscellaneous reports.
6. Whitlock, E. M., and Cleary, E. F. Planning Ground Transportation Facilities for Airports. Highway Research Record 274, 1969, pp. 1-13.
7. Analysis of Terminal Traffic, Eastern Airlines Terminal Building, John F. Kennedy International Airport. Wilbur Smith and Associates, 1968.
8. Airport Access/Egress Systems Study. Wilbur Smith and Associates, Systems Center for Transportation, Sept. 1972.

SYSTEMS ANALYSIS OF GROUND TRANSPORTATION AT MAJOR U.S. AIRPORTS

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Of the 746 airports in the United States served by commercial carriers, 20 serve 64 percent of all commercial passenger movements. Of these 20, about 15 are plagued by ground transportation congestion and delay due to the intense concentration of both vehicle and person activity influenced by the airport and its surrounding land uses. The basic congestion problem at airports relates to the difference between the capacities of its two primary interfaces used for airport operation (ground transport versus air transport). Ground transportation systems usually constrain the capacity of the overall system. This paper is based on the results of the Airport Access/Egress Systems Study (1972-1973) sponsored by the U.S. Department of Transportation. The project studied those 34 U.S. airports projected to be serving more than 2.0 million annual enplaned passengers by 1980 in order to ascertain the types and status of their ground transportation problems to be better able to recommend positive solutions. This paper reports on the data for the top 20 of these airports.

● ONE of the most perplexing transportation problems today is the fast travel time from airport to airport via a modern jetliner and the slow frustrating trip to and from the airport via ground transport. The planning process, even today, has spent too much time on the line-haul portion of trips and not enough on providing either useful modal interfaces and modal choices or other options (especially for ground transport).

The objective of this paper is to obtain a clear understanding of the present character of surface transportation congestion to and from the nation's 20 major airports. From this the type, cause, and severity of ground congestion will be identified and evaluated and non-capital-intensive approaches offered that can effectively ease these problems.

This study will show the information obtained from personal interviews at each airport and the results of an extensive survey questionnaire. Altogether, 34 individual airports were examined in the course of this study; 20 of these were selected for detailed analysis herein.

ELEMENTS OF THE PROBLEM

Activity focused on each airport and the consequent impact it causes can be indicated in a variety of ways. Aircraft movements, passenger-visitor-employee volumes with their temporal fluctuations, and public transit utilization and/or availability all influence the airport to varying degrees. These are further influenced by the particular physical characteristics present: gates, terminal design, circulation, external access, airport location, etc.

Airport Location With Respect to Demand

Airports today need more land than ever before to serve requirements dictated by larger aircraft, more travel, and environmental planning criteria and standards.

Publication of this paper sponsored by Committee on Passenger and Freight Transportation Characteristics.

With large quantities of contiguous land becoming scarce close to the city center, potential new airports are being forced farther into the suburbs and hinterlands of present metropolitan areas. Cities requiring two or more airports to serve their needs only magnify this problem of land availability. Examples of this trend are Chicago, O'Hare and Midway; Los Angeles, International and Palmdale; Washington, National, Dulles, and Friendship; New York, LaGuardia, Kennedy, and Newark; and San Francisco, International, San Jose, and Oakland.

More importantly, however, it is the spatial location with respect to other traffic generators that can often determine the degree of congestion airports may experience on their ground facilities. Airports farthest from the city center generally show more total roadway capacity to them than those airports closer to the central areas. And the nearer the airport is to the city center the greater appears to be its dependence on public transit, such as taxis, limousines, buses, and rail.

The 20 major airports range in distance from a minimum of 2.0 (Washington National) to a maximum of 17.5 miles (Detroit) from their respective city centers, with 10 miles representing the average distance. Table 1 gives various activity statistics collected at the top 20 airports.

Airline passenger orientation to the center city (CBD) influences ground access planning. With high CBD orientation, the feasibility of constructing rail rapid transit or even bus corridors is enhanced. But with many airports, the CBD trips do not predominate (Table 1). The CBD orientation is only 5 percent at Detroit, whereas LaGuardia shows a much higher attraction of 63 percent (it is known as New York's airport). On an average, the airport-oriented trips to the central areas are only 20 percent of the total trips.

External and Internal Ground Access Facilities

For all of the major airports, at least one freeway or expressway directly serves as the means of primary access and egress to the terminals (Table 2). The total number of highway lanes at each of the 20 subject airports ranges from two to five, and traffic volumes on these internal roadways vary from 20,000 to 60,000 vehicles per day, serving Philadelphia and Los Angeles, respectively. The external road system serving each airport is also important since it is found to carry much of the airport-related traffic. The percentage of vehicles with trip ends at the airports using these roadways also varies widely. The normal percentage is about 30 during typical working hours.

Vehicle congestion, however, is generally isolated at principal access interchanges to and from the airport rather than on the road itself. Other points of congestion occur at lane drops near the airport and in restricted areas where demand exceeds capacity, such as Boston's Callahan Tunnel. Maximum congestion is usually noted during the peak hours (7:00-9:00 a.m. and 4:00-6:00 p.m.).

Parking

The number of available parking spaces varies widely for each airport and is not always consistent with the magnitude of passenger activity. Chicago O'Hare, for example, the most active airport in terms of flights, passengers, and interline transfers, has about 12,000 public parking spaces available. In contrast, Denver Stapleton, with a much lower air-passenger volume, provides over 13,000 public parking spaces. Other airports affording substantial numbers of public parking spaces are John F. Kennedy (12,200), Los Angeles International (11,400), and Dallas Love Field (10,100). Of the airports studied, Minneapolis-St. Paul provided the fewest parking spaces at 3,700. An expansion program is now under way for more public parking at Minneapolis, however.

The Federal Aviation Administration has estimated 1980 parking needs for the largest airports. They range from 900 spaces per million annual enplaning passengers at the New York airports to 1,200 at Cincinnati. The FAA roughly estimates that 1.5 parking spaces be provided per total peak-hour passenger.

Table 1. Person activity at U.S. airports.

Airport	1970 Metropolitan Area Population (thousands)	Central Location With Respect to CBD	Central Area Orientation[a] (percent)	Distance to CBD (miles)	Passengers (millions)		
					Enplaned	Deplaned	Total
Chicago O'Hare	6,979	No	N.A.	16.5	14.8	15.1	29.9
Los Angeles	7,032	Yes	15	11.0	10.4	10.4	20.8
New York John F. Kennedy	11,529	No	47	11.5	10.1	9.1	19.2
Atlanta	1,390	No	24	7.5	9.0	9.1	18.1
San Francisco	3,110	No	25	12.0	7.1	7.1	14.2
New York LaGuardia	11,529	Yes	63	5.5	6.7	6.0	12.7
Miami	1,268	No	35	10.0	5.6	5.6	11.2
Dallas Love Field	1,556	No	N.A.	5.8	5.5	5.7	11.2
Washington National	2,861	Yes	25	2.0	5.4	5.4	10.8
Boston Logan	2,754	Yes	14	2.5	4.8	4.8	9.6
Denver Stapleton	4,200	No	30	7.5	3.0	3.9	7.8
Detroit Wayne County	1,857	No	5	17.5	3.6	3.6	7.2
Newark	11,529	Yes	61	10.5	3.3	3.2	6.5
Philadelphia	4,818	No	14	6.3	3.3	3.1	6.4
Pittsburgh	2,401	No	21	12.0	3.2	3.2	6.4
St. Louis Lambert Field	2,363	No	10	12.5	3.0	3.0	6.0
Minneapolis-St. Paul	1,814	No	N.A.	7.3	2.9	2.9	5.8
Cleveland Hopkins	2,064	No	N.A.	10.7	2.5	2.4	4.9
Seattle-Tacoma	1,422	No	17	12.0	2.4	2.3	4.7
Houston	1,985	No	38	15.5	2.3	2.3	4.6

Airport	Inter-Airline Transfers (percent)	Number of Employees at Airport			
		Airlines	Airport Workers	Other	Total
Chicago O'Hare	50.0	14,000	2,150	1,300	17,450
Los Angeles	26.0	29,000	4,000	4,000	37,000
New York John F. Kennedy	25.0	15,000	700	7,870	23,570
Atlanta	60.0	15,000	2,500	—	17,600
San Francisco	18.0	17,400	2,975	—	20,375
New York LaGuardia	11.0	2,210	290	1,000	3,500
Miami	20.0	23,900	9,240	—	33,140
Dallas Love Field	10.0	10,420	2,020	30	12,470
Washington National	9.0	4,680	2,180	4,690	11,550
Boston Logan	14.2	7,700	310	2,010	10,020
Denver Stapleton	30.0	6,000	155	—	6,155
Detroit Wayne County	10.0	N.A.	N.A.	N.A.	6,000
Newark	13.0	1,640	140	1,560	3,340
Philadelphia	14.0	3,000	200	1,000	4,200
Pittsburgh	30.0	2,100	2,000	—	4,100
St. Louis Lambert Field	35.0	N.A.	N.A.	N.A.	2,500
Minneapolis-St. Paul	3.5	8,000	1,500	300	9,800
Cleveland Hopkins	37.5	3,000	1,000	—	4,000
Seattle-Tacoma	6.0	4,280	1,810	—	6,090
Houston	10.0	N.A.	N.A.	N.A.	4,100

Note: Unless otherwise indicated, the data were collected during 1971. N.A. = not available.

[a]Central area orientation is defined as the area where most of the air travelers originate or are destined.

Table 2. Public transit and parking facilities at airports.

Airport	Number of Transit Lines[a]				Type of Parking (number of spaces)						
					Lot		Garage		Curb		
	Bus	Limousine	Taxi	Rail	Short Term	Long Term	Short Term	Long Term	Short Term	Long Term	Total
Chicago O'Hare	2	2	3	None	4,800	1,200	—	—	—	—	6,000
Los Angeles	1	2	1	None	900	5,500	1,000	4,000	—	—	11,400
New York John F. Kennedy	4	8	Many	None	6,500	5,700	—	—	—	—	12,200
Atlanta	1	1	50	None	2,140	2,130	1,200	—	—	—	5,470
San Francisco	2	10	1	None	390	1,480	3,200	—	—	—	5,070
New York LaGuardia	3	10	Many	None	6,110	—	—	—	—	—	6,110
Miami	1	1	Many	None	—	1,530	—	4,510	50	—	6,090
Dallas Love Field	1	2	4	None	540	7,370	—	2,200	—	—	10,110
Washington National	2	1	Many	None	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	7,300
Boston Logan	4	5	Many	Yes	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	8,290
Denver Stapleton	3	1	3	None	—	2,200	9,000	1,900	—	—	13,100
Detroit Wayne County	2	5	3	None	360	1,880	—	3,150	50	—	5,440
Newark	10	5	Many	None	920	5,500	—	—	—	—	6,420
Philadelphia	1	3	2	None	740	6,090	—	—	—	—	6,830
Pittsburgh	1	1	1	None	650	3,000	40	—	150	—	3,840
St. Louis Lambert Field	2	3	5	None	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	5,050
Minneapolis-St. Paul	1	3	—	None	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	3,700
Cleveland Hopkins	—	1	1	Yes	210	1,490	—	2,400	—	—	4,100
Seattle-Tacoma	2	—	1	None	—	—	—	4,800	—	—	4,800
Houston	—	—	Many	None	300	3,500	N.A.	1,500	N.A.	N.A.	5,300

Airport	Gross Parking Revenue (millions)	Linear Feet of Curb			Multiple Access[b]	Number of Access Roads to Airport Terminal Area[c]	Significant Congestion on Internal Roadways[d]	Significant Congestion on External Roadways[e]
		Enplaning	Deplaning	Total				
Chicago O'Hare	N.A.	2,550	1,850	4,400	No	1	Yes	No
Los Angeles	7.318	3,500	3,500	7,000	Yes	2	Yes	Yes
New York John F. Kennedy	N.A.	4,000	3,600	7,600	Yes	2	Yes	Yes
Atlanta	2.024	900	1,200	2,100	No	1	Yes	Yes
San Francisco	4.000	1,800	1,800	3,600	No	1	No	Yes
New York LaGuardia	N.A.	1,500	900	2,400	Yes	3	Yes	Yes
Miami	1.715	3,750	1,800	5,550	No	1	Yes	Yes
Dallas Love Field	2.739	900	900	1,800	No	1	No	No
Washington National	2.004	1,300	1,200	2,500	Yes	2	Yes	Yes
Boston Logan	4.459	500	900	1,400	Yes	2	No	Yes
Denver Stapleton	2.448	500	500	1,000	Yes	2	No	No
Detroit Wayne County	3.000	600	400	1,000	Yes	2	Yes	Yes
Newark	N.A.	900	900	1,800	No	1	No	No
Philadelphia	2.902	400	1,100	1,500	No	1	Yes	Yes
Pittsburgh	1.234	900	1,200	2,100	Yes	2	Yes	Yes
St. Louis Lambert Field	2.000	800	800	1,600	No	1	Yes	Yes
Minneapolis-St. Paul	1.250	800	800	1,600	No	1	No	No
Cleveland Hopkins	1.200	650	650	1,300	No	1	No	No
Seattle-Tacoma	1.500	1,000	1,000	2,000	Yes	2	No	No
Houston	2.147	600	900	1,400	Yes	2	No	No

Note: Unless otherwise indicated, all data were collected during 1971. N.A. = not available.

[a]Includes all transit service in the metropolitan area.
[b]Airport with more than one highway serving it.
[c]Airport served with two or more roadway facilities.
[d]Includes all highway facilities within the airport complex.
[e]Includes those highways affording access to the airport.

The storage of private vehicles for short- and long-term parkers is also a critical problem. When parkers cannot find a parking space, they usually recirculate or double-park within the airport complex until a vacancy occurs. This reduces the effective capacity of the airport roadways and results in delays to other vehicles. An inventory of existing parking spaces for each of the study airports is given in Table 2.

Revenues from parking comprise a significant and important source of income for the airports, and for this reason it is difficult to reduce vehicle demand by reducing parking supply or pricing parking above existing rates. Annual parking revenues collected for each of the subject airports during 1971 range from $1.2 million at Cleveland Hopkins to about $7.3 million at Los Angeles International.

Existing parking charges at the principal airports differ significantly between short- and long-term parking. Most of these airports charge approximately 50 cents per hour for short-term parking and between $1.00 and $3.00 per day for 24-hour parking. Long-term parkers are often encouraged by lower charges to use remote parking lots. Buses and other forms of transit frequently are employed to connect the remote parking facilities with terminal areas. At two new major facilities (Kansas City International and Dallas-Fort Worth) remote parking is being considered with the same kind of importance as central terminal parking.

Curb Frontage

Many passengers are dropped off or collected at curb locations at airline terminal facilities. Where there is insufficient curb space to meet demand, queuing of vehicles results causing congestion that can extend to the central terminal roadways. This study found that enplaning passengers require less total curb space (due to less time being spent in this maneuver) than do deplaning passengers. Enplaning passengers and their baggage are usually deposited immediately upon entering the curb location, whereas vehicles waiting to transport deplaning passengers frequently accumulate substantially longer parking times while waiting for passengers to emerge from the air terminal. Major reasons for this seem to be the time needed to collect and load baggage, make telephone calls, etc. Field studies have shown that, on an average, enplaning passengers use the curb for about 2 minutes per automobile, compared with about 3 minutes for deplaning passengers. For other modes, deplaning passengers also take longer to interface with ground transportation.

Kennedy International Airport provides the most curb space, with 3,600 linear feet for deplaning and 4,000 feet for enplaning passengers. This is because there are actually 10 separate terminals. Detroit has the smallest amount of deplaning curb frontage with only 400 linear feet. The amount of enplaning and deplaning frontage provided in each airport varies with the terminal configuration. Illustrative of this are the Kennedy, Dallas Love, and Detroit Metropolitan Airports, which all have imbalances in the amount of curb frontage provided for enplaning and deplaning passengers.

Passengers, Visitors, and Employees

Chicago's O'Hare Airport generates the greatest number of total annual airport passengers, almost 30 million, while Houston Intercontinental Airport generates the least at about 4.6 million (Table 1). The total number of passengers is important since they usually require ground transport services to and from the airport. Yet the intensity of interline transfers at the airports reduces this overall need because those transferring passengers normally remain within the airport terminal complex and do not impact the highways serving the terminals. For example, Chicago and Atlanta are reported to have about 50 and 60 percent respectively of total passengers as interline transfers. Minneapolis-St. Paul shows the least amount of transfers with 3.5 percent. When the total annual passengers are adjusted for transfers, Los Angeles International depicts the greatest potential demand on ground transport facilities, with Cleveland Hopkins the least.

Visitors also account for a great deal of airport activity. With each airline passenger there are between 1.0 and 1.5 airport visitors. Naturally, there is much variance in this statistic at each airport, especially when one includes the time of day and day of week.

Many of the 20 airports employ more persons than the total work force of a city of about 500,000 population (Table 1). Each airport employs about 1.0 person for each daily air passenger using the airport. Los Angeles, Miami, Kennedy, and San Francisco, for example, employ 37,000, 33,000, 24,000, and 20,000 persons respectively.

Typically, the majority of visitor and airline passenger activity occurs between 7:00 and 9:00 a.m. and 4:00 and 6:00 p.m. on weekdays. Most of the 20 airports work on a 3-shift basis, with the day shift comprising 30 to 65 percent of the total activity. The early evening shift comprises 20 to 50 percent of total activity, and the late shift comprises only 10 to 20 percent of the passenger, visitor, and employee activity. Airport employees generally arrive and depart at about the same time as other workers in non-airport-related jobs, and this occurs somewhat simultaneously with the peak demand for air travel. This peaking tends to overlap other peak-hour travel, causing some additional delay and congestion on regional highways.

Aircraft Movements

Chicago, as expected, has the greatest number of aircraft movements, with Houston Intercontinental the least (Table 3). General aviation activity at the 20 airports ranges from 10 to about 50 percent of total aviation movements but only accounts for a fraction of the total number of passengers served by commercial flights.

Cargo Operations

The amount and location of cargo activity is significant since it can interfere with normal passenger processing if not located properly. Separate cargo access is provided at only six airports: Chicago, Los Angeles, San Francisco, Pittsburgh, Cleveland, and Houston. The magnitude of cargo operations is closely related to the markets served. Presently, annual cargo operations range from 835,000 tons at Kennedy to 34,000 tons at Houston. It is expected that air freight movements will escalate at a faster rate than air passenger activity.

Travel Characteristics

The surveyed airports are often the single most active land-use facility in the entire metropolitan area. Vehicle-miles to and from the airports reflect this comparable attraction. Also, there is a tremendous local impact on the highway system at peak periods, requiring a major portion of roadway capacity devoted to airport-related use. This fact is accentuated with proximity to the airport.

Discussions with airport officials revealed that air travel is highly seasonal, with variations in demand occurring mainly because of business and non-business trip purposes. Variations within the week are not too significant, although Saturday usually produces the least amount of air travel. Sunday usually experiences the most traffic at airports.

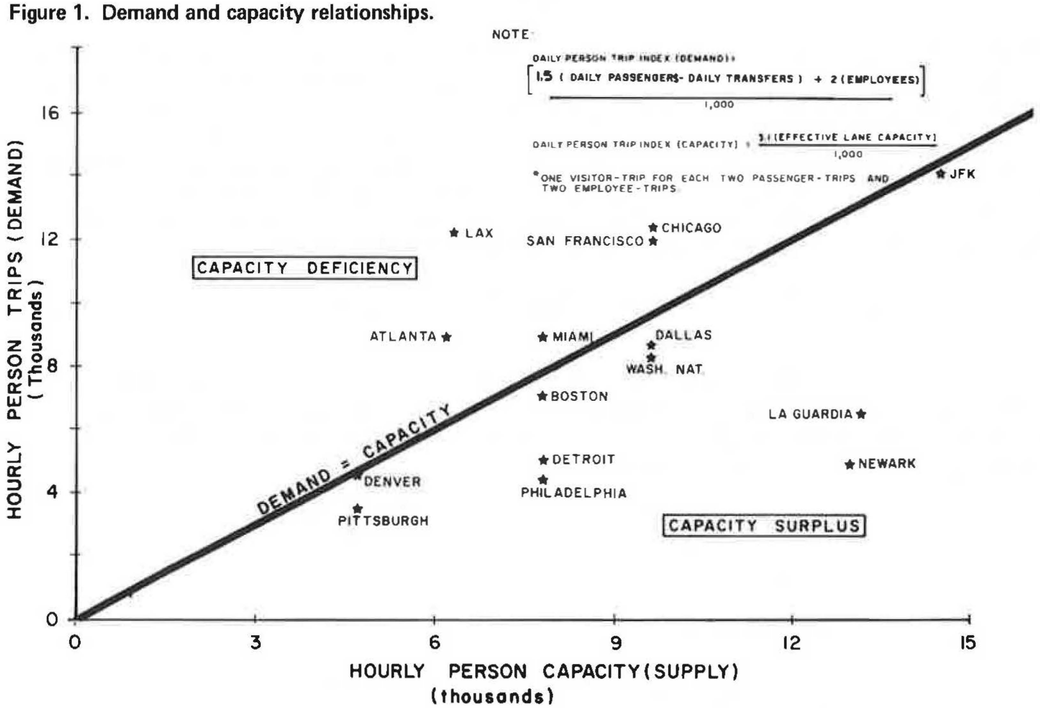
Distribution of travel among private automobile, taxi, public transit, helicopter, etc., depends on the availability, level of service, and cost of these services. Most vehicular traffic at airports consists of the private car, and this accounts for nearly 70 percent of total passenger arrivals at most major airports. Buses, taxis, limousines, and trucks typically account for 13, 10, 4, and 3 percent of the remaining total respectively.

While all of the surveyed airports have public bus service, only Boston and Cleveland have a passenger-carrying rail facility, although more are being actively planned. Boston's rail facility does not directly serve the airport and uses a bus to shuttle passengers between the rail station and airport terminals. The transit services provided at major U.S. airports are given in Table 2. Chicago, New York, San Francisco, and Los Angeles have passenger helicopter service as support to their ground transport systems. Patronage is relatively low on this mode, primarily because of high costs and restricted availability.

Table 3. Aircraft and cargo statistics (1971 data).

Airport	Aircraft Movements			Number of Gates	Annual Tonnage of Cargo	Cargo Access	
	Commercial	General Aviation	Total			Off-Site Cargo Staging Areas	Separate Cargo Access
Chicago O'Hare	589,300	52,100	641,400	72	720,000	No	Yes
Los Angeles	460,000	67,000	527,000	78	567,000	Yes	Yes
New York John F. Kennedy	302,900	38,900	341,800	124	834,700	Minimal	No
Atlanta	391,900	45,900	437,800	72	344,500	Yes	No
San Francisco	297,300	64,000	361,300	52	296,500	Yes	Yes
New York LaGuardia	247,700	68,900	316,600	41	43,300	No	No
Miami	234,000	108,000	342,000	82	289,500	No	No
Dallas Love Field	291,700	103,000	394,700	55	48,000	No	No
Washington National	224,300	111,100	335,400	40	90,200	No	No
Boston Logan	245,800	25,500	271,300	64	135,000	Yes	No
Denver Stapleton	184,700	158,700	343,400	35	68,700	No	No
Detroit Wayne County	193,700	78,100	271,800	49	125,100	Yes	No
Newark	143,400	44,600	188,000	32	135,000	Minimal	No
Philadelphia	215,400	76,800	292,200	39	147,000	Minimal	No
Pittsburgh	195,500	82,000	277,500	38	77,700	Yes	Yes
St. Louis Lambert Field	188,100	110,200	298,300	34	85,000	Minimal	No
Minneapolis-St. Paul	125,000	96,000	221,000	38	65,000	Yes	No
Cleveland Hopkins	128,700	83,200	211,900	40	102,100	Minimal	Yes
Seattle-Tacoma	114,400	33,900	148,300	35	91,000	No	No
Houston	107,000	23,300	130,300	40	24,000	No	Yes

Figure 1. Demand and capacity relationships.



DEMAND-SUPPLY RELATIONSHIPS

The establishment of an analytical relationship between the demand for ground transport and the capacity of existing transportation facilities to meet this demand is useful in categorizing need. This can be used to denote the extent of congestion. Therefore, an index of demand was established and related to existing and proposed access facilities. To establish relative measures of the magnitude of particular congestion problems, ratios comparing activity levels to capacity indices were calculated for each of the subject airports.

The demand index is a function of the number of person-trips oriented to the airports on a daily basis. This relates to the level of service provided at each airport in terms of employment, frequency of airline flights, cities served, location of airport, cost of travel, and overall length (in time) of the air trips, along with other variables. After reviewing this information, the most significant planning variables were found to be numbers of visitors, employees, and passengers. From this, the "person-demand index" (PDI) emerged:

$$\text{PDI} = \frac{[1.5\ (\text{daily passengers - interairline transfers}) + 2\ (\text{number of employees})]}{1{,}000} \qquad (1)$$

"Supply" in this context is the amount of ground capacity available and is not a random variable. The total number of highway lanes serving each airport was counted, applying some judgment where these roads did not provide a primary access facility. On a broad basis, at-grade highways with traffic signals were assumed to have a capacity for moving about 500 vehicles per lane per hour. Grade-separated facilities (expressways) were estimated to be capable of moving approximately 1,000 vehicles per lane per hour. From this, and the fact that the average airport generates a little more than 3 persons per vehicle, the "person capacity index" (PCI) was developed:

$$\text{PCI} = \frac{3.1\ (\text{effective lane capacity in vehicles per hour})}{1{,}000} \qquad (2)$$

Figure 1 shows results of the application of these formulas. It reveals that Los Angeles has the greatest ground access problem of the U.S. airports and Newark Airport is relatively uncongested because of substantial highway capacity. Indices of person supply and demand for the major airports are as follows:

Airport	Demand Index
Los Angeles	2.00
Atlanta	1.50
Chicago O'Hare	1.30
San Francisco	1.20
Miami	1.20
New York John F. Kennedy	1.00
Denver Stapleton	1.00
Boston Logan	0.94
Dallas Love Field	0.90
Washington National	0.90
Pittsburgh	0.70
Detroit Wayne County	0.63
Philadelphia	0.62
New York LaGuardia	0.48
Newark	0.38

Besides supplying enough roadway capacity to meet demand, this study found other important relationships. Figure 2, for example, shows that 17 of the 20 airports generally provide more vehicle parking spaces than the FAA has recommended as a design standard. It also indicates that O'Hare, Atlanta, and San Francisco show major deficiencies in meeting this standard. Figure 3 shows the relation between effective

Figure 2. Air passengers and airport parking spaces.

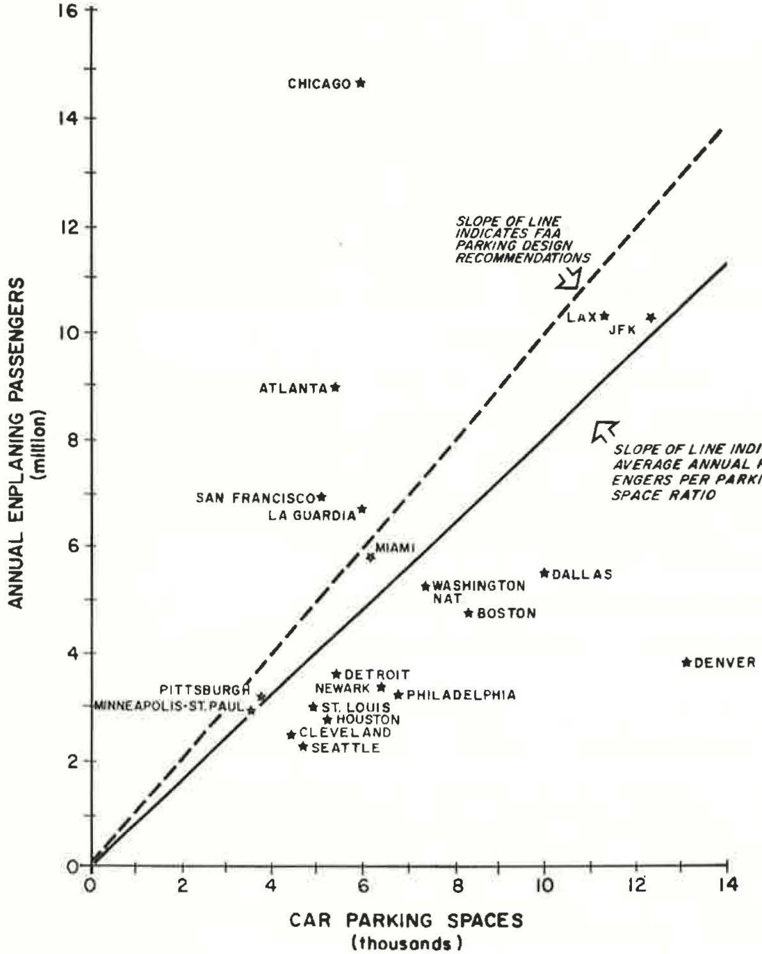
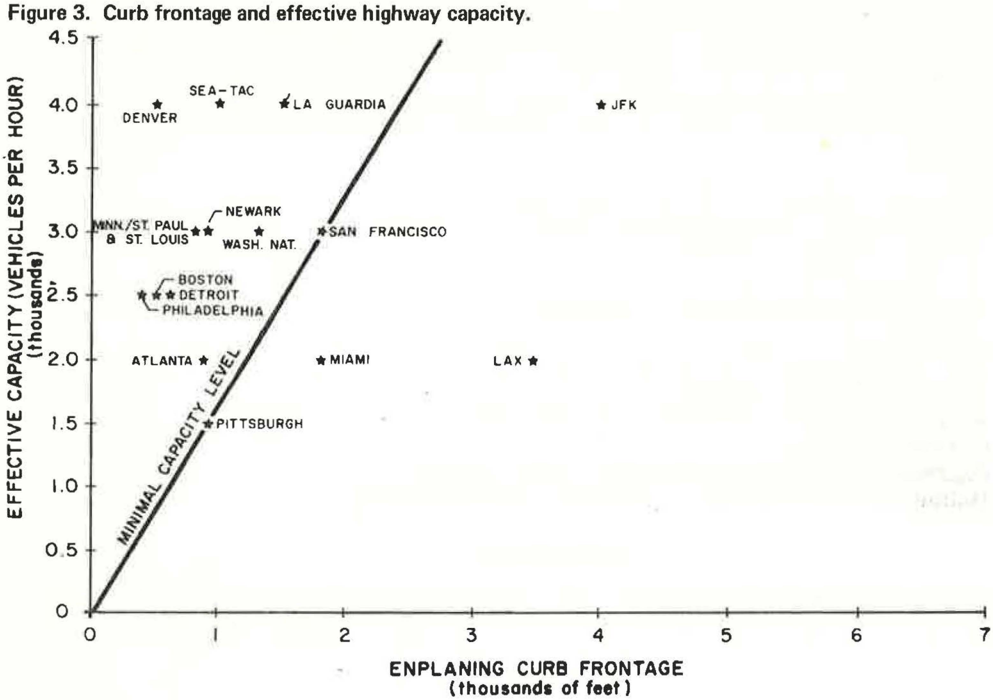


Figure 3. Curb frontage and effective highway capacity.



roadway capacity and enplaning curb frontage. It reveals that the Los Angeles and Atlanta airports, for example, both have an effective airport roadway capacity of 2,000 vehicles per hour, and yet Los Angeles has about 4,000 linear feet of enplaning curb frontage compared to less than 1,000 for Atlanta. For policy considerations, limiting curb frontage may be one means of controlling vehicles. Finally, Figures 4 and 5 show the relationships between enplaning passengers and enplaning curb frontage and between deplaning passengers and deplaning curb frontage. They show generally that the same space is provided for both, which is not consistent with the previous observation that deplaning passengers generally require more time and have more curb frontage.

FUTURE DEMAND

In anticipation of future air travel demands, most of the major airports are planning extensive expansion. In some cases these plans include the complete rebuilding of terminal areas and construction of new airfields. Provisions are being made at most airports to accommodate larger aircraft. Reliable projections of aircraft movements by 1980 reflect increases of as much as 90 percent over present conditions. Passenger projections for this same period indicate that activity at airports is expected to at least double in many cases within the next 7 years (Table 4).

FINDINGS AND RECOMMENDATIONS

Four broad, yet somewhat specific, problem areas were identified (Fig. 6) from this study:

1. Origins and destinations of air travelers presently oriented to and from the airports are too dispersed to economically justify either rapid transit corridor or other main-line investments;
2. Limited availability or intensive use of primary or secondary access and egress routes to most airports places substantial demand on a single road system;
3. Too much off-street parking is being provided in the central terminal area in relation to the capacity of the road system to serve it adequately; and
4. Too much vehicular activity is concentrated at or near the enplaning and deplaning curbs in the terminal areas, which reduces effective capacity.

Candidate operational experiments to relieve congestion at the hub airports previously identified with problems were conceived. To accomplish the intended goals, it is clear that without capital-intensive projects the remaining alternatives would best be the application of traffic engineering techniques to obtain more efficient use of existing roadways or to alter travel patterns and habits of the air travelers wherein more off-peak highway capacity would be used. Utilizing this logic and the cost-effective implications of initiating and completing the projects produced the following 12 possibilities:

1. Highway surveillance and guidance control;
2. Coordination of existing traffic signals;
3. Multiple-access roadways;
4. Preferential lane use;
5. Bus and limousine off-peak marketing;
6. Off-peak air service;
7. Dial-a-ride marketing (demand-activated);
8. Motorist advisory system;
9. Segregated traffic in central terminal area;
10. Garage check-in;
11. Segregated pedestrian and vehicular traffic; and
12. Balancing central terminal area and remote parking.

CONCLUSIONS

This study accentuates the fact that many low-cost measures can be used at airports to alleviate ground traffic congestion and delay. It maintains that these measures can

Figure 4. Curb frontage and enplaning passengers.

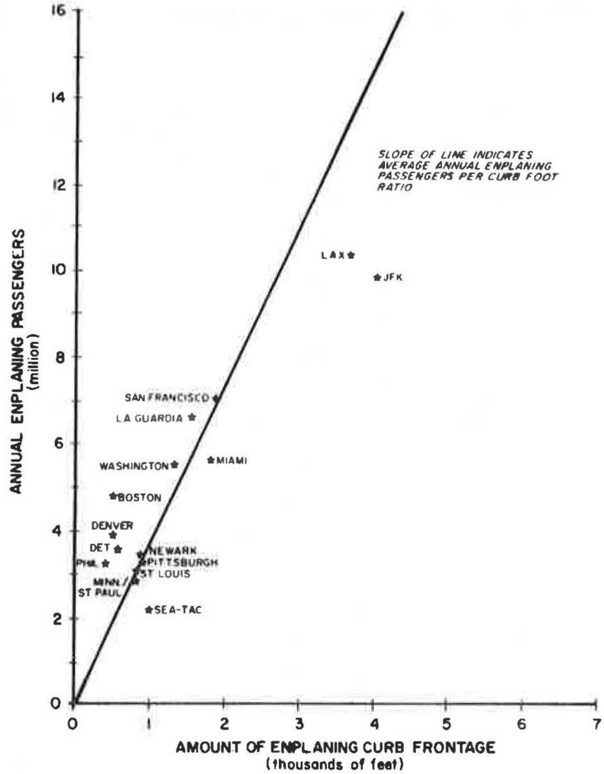


Figure 5. Curb frontage and deplaning passengers.

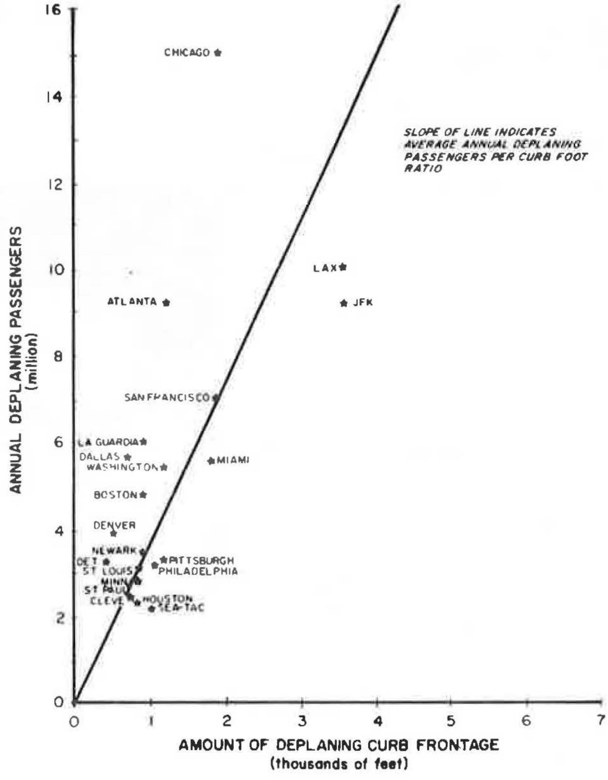


Table 4. Projected airport statistics and planned facilities.

Airport	Aircraft Movements[a] Commercial	General Aviation	Total	Passengers[b] (millions) Explaned	Deplaned	Total	New or Relief Airport Planned	Status of Rapid Transit for Metropolitan Area: Existing or Under Con-struction	Under Study	Pro-posed	None
Chicago O'Hare	N.A.	N.A.	N.A.	30.0	30.0	60.0	Study	x	—	—	—
Los Angeles	550,000	30,000	580,000	20.0	20.0	40.0	Yes	—	—	x	—
New York John F. Kennedy	230,000	60,000	290,000	17.5	17.5	35.0	Yes	x	—	—	—
Atlanta	N.A.	N.A.	664,000	20.0	20.0	40.0	Yes	—	—	x	—
San Francisco	N.A.	N.A.	382,000	15.5	15.5	31.0	No	x	—	—	—
New York LaGuardia	235,000	67,000	302,000	12.0	12.0	24.0	Yes	x	—	—	—
Miami	405,000	80,000	485,000	12.5	12.5	25.0	Yes	—	—	x	—
Dallas Love Field	—	210,000	210,000	—	—	—	Yes	—	—	x	—
Washington National	240,000	100,000	340,000	N.A.	N.A.	16.0	No	x	—	—	—
Boston Logan	321,000	73,000	394,000	8.3	8.3	16.6	No	x	—	—	—
Denver Stapleton	306,000	165,000	471,000	N.A.	N.A.	19.0	No	—	x	—	—
Detroit Wayne County	380,000	61,000	441,000	17.0	17.0	34.0	No	—	—	x	—
Newark	207,000	56,000	263,000	9.5	9.5	19.0	Yes	—	x	—	—
Philadelphia	230,000	170,000	400,000	7.0	7.0	14.0	No	x	—	—	—
Pittsburgh	246,000	139,000	385,000	5.8	5.8	11.6	Study	—	x	—	—
St. Louis Lambert Field	250,000	170,000	420,000	8.5	9.0	17.5	Yes	—	x	—	—
Minneapolis-St. Paul	243,000	22,000	265,000	5.4	7.6	13.0	Study	—	—	—	x
Cleveland Hopkins	138,500	131,500	270,000	5.5	5.5	11.0	Study	x	—	—	—
Seattle-Tacoma	210,000	40,000	250,000	N.A.	N.A.	14.0	No	—	—	—	x
Houston	131,000	52,000	183,000	6.5	6.5	13.0	No	—	x	—	—

Airport	Potential of Rapid Transit to Serve Airport by 1980: Good	Fair	Limited	Major Improvements Planned: Road-way	Park-ing Space	Curb Front-age	Type of Congestion[c]: Air-space	Air-field	Baggage Claim Area	Ter-minal Func-tions	Road-way	Pedes-trian	Parking
Chicago O'Hare	x	—	—	Yes	Yes	No	(1)	—	—	—	2	—	—
Los Angeles	—	—	x	Yes	Yes	Yes	4	3	—	—	(1)	2	5
New York John F. Kennedy	x	—	—	Yes	Yes	Yes	—	1	—	—	1	—	1
Atlanta	x	—	—	Yes	No	No	7	1	2	3	(5)	4	6
San Francisco	x	—	—	Yes	Yes	Yes	4	1	6	5	3	7	(2)
New York LaGuardia	x	—	—	Yes	Yes	Yes	—	1	—	—	1	—	1
Miami	—	x	—	Yes	Yes	Yes	6	2	(1)	4	3	5	7
Dallas Love Field	x	—	—	No	No	No	—	—	1	2	—	—	—
Washington National	x	—	—	Study	Study	Study	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Boston Logan	x	—	—	Yes	Yes	Yes	—	—	—	1	—	—	—
Denver Stapleton	—	—	x	No	No	Yes	5	6	4	7	(1)	2	3
Detroit Wayne County	—	x	—	Yes	Yes	Yes	1	(3)	6	4	(7)	5	(2)
Newark	x	—	—	Yes	Yes	Yes	1	1	1	—	1	—	1
Philadelphia	x	—	—	Study	Yes	Yes	—	1	1	1	1	—	1
Pittsburgh	—	—	x	Yes	Yes	Yes	5	3	4	6	2	7	(1)
St. Louis Lambert Field	—	—	x	No	Yes	Yes	—	4	2	3	(1)	—	—
Minneapolis-St. Paul	—	—	x	Yes	Yes	No	5	2	3	6	4	7	(1)
Cleveland Hopkins	x	—	—	Yes	No	No	7	6	(1)	3	2	5	4
Seattle-Tacoma	—	—	x	No	Yes	Yes	7	6	1	3	2	5	4
Houston	—	x	—	Yes	Yes	Yes	7	6	1	3	2	5	4

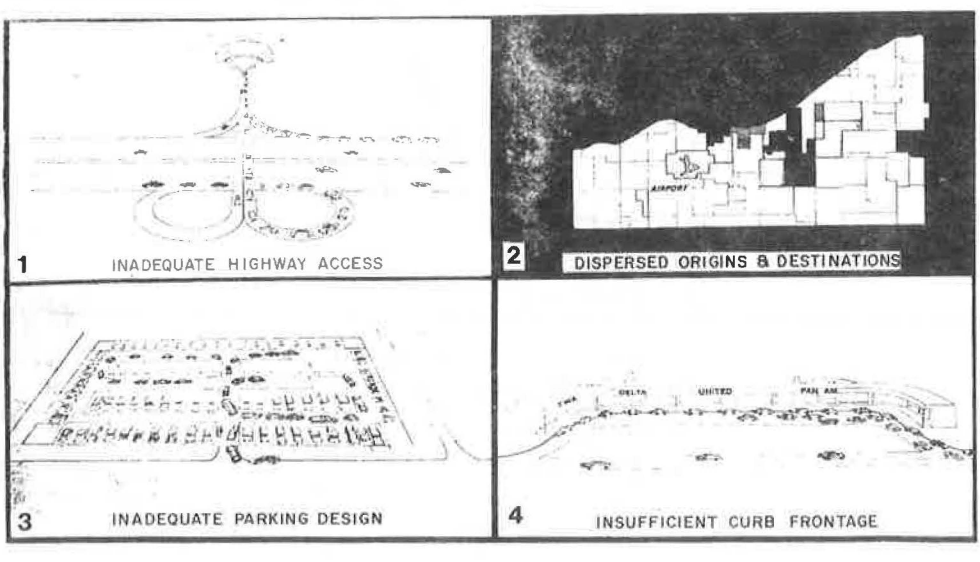
Note: N.A. = not available.

[a]Estimated 1,980 aircraft movements.

[b]Estimated 1,980 passenger activity.

[c]Numerals denote intensity of the problem at the airport, 1 indicating the most important problem. Duplication of any number indicates equal intensity of the problems. A number in parentheses indicates the area of congestion that results in the most user delay. A blank space indicates that the interviewee did not consider that area a problem.

Figure 6. Major reasons for airport ground delays.



often be more cost-effective than some major capital-intensive construction efforts to ultimately improve roadway capacity. These measures must be properly marketed to travelers through a public relations and advertising program to ensure high use and acceptability on a long-term basis. The measures, furthermore, should be designed to directly address motivation and need for travel—usually a function of time or cost. These measures, finally, should either reduce the travel time significantly or offer service at a low cost or both.

With specific reference to current issues of travel constraint—i.e., environmental concerns and the energy shortage—operational experiments suggested herein will still apply. The non-capital-intensive character of the experiments, added to values of optimizing existing transportation facilities and services, should positively influence implementation of some experiments to improve ground access and egress at selected hub airports.

ACKNOWLEDGMENTS

The authors wish to express appreciation to H. K. Schaeffer and others at the Transportation Systems Center of the U.S. Department of Transportation for their assistance in the conduct of the study.

REFERENCES

1. Brown, J. F. Airport Accessibility Affects Passenger Development. Jour. Aero-Space Transport Division, ASCE, Vol. 91, No. AT-1, Proc. Paper 4302, April 1965, pp. 47-58.
2. De Neufville, R. , Moore, H., and Yaner, J. Optimal Use of Vehicular Systems in the Design of Airport Terminals. Civil Engineering Systems Laboratory, Massachusetts Institute of Technology, 1968.
3. Evans, H. K. Balanced Highway-Airport Design. Transportation Engineering Jour., ASCE, Vol. 95, No. TE-1, Proc. Paper 6420.
4. Harris, R., and Michalski, C. Planning and Design of Airport Terminal Parking Facilities. ITE Proc. 1959.
5. Homburger, W., and Edgar, W. Automobile Parking Requirements at Airports. Jour. Aero-Space Transport Division, ASCE, Oct. 1964.
6. Horonjeff, R. Planning and Design of Airports. McGraw-Hill, New York, 1962.
7. Keefer, L. Urban Travel Patterns for Airports, Shopping Centers and Industrial Plants. NCHRP Rept. 24, 1966.
8. Lardiere, S. C., and Jarema, F. E. Impact of Projected Air Travel Demand on Airport Access. Highway Research Record 274, 1969, pp. 21-34.
9. Park, R. E. Airport Accessibility and Air Passengers. Jour. Aero-Space Transport Division, ASCE, Vol. 92, No. AT-2, Nov. 1966.
10. Silence, S. M. A Preliminary Look at Ground Access to Airports. Highway Research Record 274, 1969, pp. 14-20.
11. Voorhees, A. M. Airport Access Circulation and Parking. Jour. Aero-Space Transport Division, ASCE, Vol. 92, No. AT-1, Proc. Paper 4611, Jan. 1966, pp. 63-75.
12. Whitlock, E. M., and Cleary, E. F. Planning Ground Transportation Facilities for Airports. Highway Research Record 274, 1969, pp. 1-13.
13. Whitlock, E. M., and Sanders, D. B. The Role of General Aviation: Present and Future. American Society of Civil Engineers, Oct. 1973.
14. Whitlock, E. M., Mirsky, H. M., and La Magna, F. Ground Transportation Planning Implications of Airline Shuttle Passengers. Presented at HRB 53rd Annual Meeting and included in this Record.

METHOD FOR EVALUATING METROPOLITAN ACCESSIBILITY

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Improving the quality of urban life requires not only the provision of employment, medical, educational, and recreational opportunities but also a convenient means of access to these facilities for all citizens. This study reports on a prototypical application of a new methodology, called Special Area Analysis (SAA), designed to assess the quality of accessibility in metropolitan areas. Starting with a definition of accessibility in functional terms, this SAA develops measures that focus on the level of accessibility afforded by Boston's present, planned, and programmed urban transportation systems to such essential urban activity centers as major employment districts, medical, recreational, and educational facilities, the central business district, and the airport. In addition, the methodology is applied toward an evaluation of the level of accessibility afforded to specific population subgroups such as low-income and zero-car households. This study demonstrates that the SAA methodology is a useful evaluation tool for use by metropolitan area transportation planning agencies.

•ACCESSIBILITY has generally been defined as some measure of spatial separation of human activities. Because transportation systems connect spatially separated activities, accessibility is of interest in planning for transportation systems. This paper reports on the development and application of a method to analyze metropolitan accessibility conditions.

The method grew out of an interest by the U. S. Department of Transportation in exploring possibilities for conducting accessibility analyses as part of the metropolitan area component of the 1974 National Transportation Study. The Department supported development of the necessary computer software and the conduct of a pilot study in the Boston area after it had initiated the necessary conceptual and organizational work itself. The pilot study is called a Special Area Analysis (SAA) because it is a special set of information that supplements the more aggregate type of analysis done in the National Transportation Study. [The accessibility studies reported here represent only one component of Special Area Analysis. Other methodologies in the SAA package include air quality analysis, noise analysis, and dislocation impact analysis (1).]

The purpose of this project was twofold:

1. To demonstrate the feasibility and desirability of the SAA accessibility methodology, and
2. To provide useful information to transportation planning agencies at the local, state, and federal levels.

This Special Area Analysis focuses on the level of accessibility afforded by Boston's present, planned, and programmed urban transportation systems to such essential urban activity centers as employment districts, medical, recreational, and educational facilities, the central business district, and the airport.

Computer software for the study was developed under separate contract funded by the U. S. Department of Transportation. Production runs with the software were made by the Urban Planning Division of the Federal Highway Administration. Conduct of the study thus involved the cooperation and participation of three state agencies, one regional

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Evaluation.

agency, several DOT agencies, and several private consultants.

METHODOLOGY

It was decided to measure spatial separation by travel time over highway and transit networks separately. Cross-modal comparisons could then be made and results could be expressed in the easily understood and commonly experienced terms of travel time. In addition, it was decided to use cumulative percentages of population within various travel time contours of important metropolitan activities as the central expression of accessibility. This is a functional measure of accessibility. It defines the percentage of resident population that has access to specific functional human activities (e.g., jobs, medical facilities, recreational facilities).

Thus there are three essential components of the functional accessibility measure: the locations and characteristics of the resident population, the locations of important metropolitan area activity centers, and the characteristics of the existing transportation system. Changes in accessibility may be caused by changes in any one or more of these components. Therefore, it is difficult to ascribe access changes precisely to any one of the component factors unless two of them are known to be constant over the relevant analysis period.

It should also be noted that the accessibility measure employed in the SAA does not directly describe the actual use of particular modes in the metropolitan area. It simply measures the availability (in terms of the travel times by auto and transit) of transportation services to specific population subgroups. In Boston's Special Area Analysis, a notion of modal use is indirectly included in the accessibility measures because the auto travel times employed in the analysis are adjusted to account for congestion effects and the transit travel times employed reflect existing frequency of service.

In view of this discussion, it is important to point out the usefulness and limitations of the SAA accessibility data. In its present form, the SAA provides a general picture of regional access conditions by auto and transit in selected analysis years. This is particularly useful to state and federal planning agencies in comparing access conditions in different cities.

For planning agencies at the state and local levels, the SAA can give some indication of transportation system goal achievement if goals can be stated in terms of accessibility measures. Thus a comparison of the accessibility consequences of alternative transportation system plans can be related to transportation system costs to derive measures of relative cost-effectiveness in access terms. It should be remembered, however, that the Special Area Analysis accessibility measures are aggregate measures and as such are of limited utility for subarea or subsystem evaluation. The accessibility measures are probably best applied as total plan evaluation tools and as a device for comparing accessibility conditions in different cities.

In the Boston pilot study three separate sets of accessibility conditions were examined: 1970 and two alternative sets for 1980. The analysis therefore shows whether metropolitan access conditions change given two alternative courses of action by 1980. The two 1980 conditions are called planned and null. The planned situation basically reflects decisions made in the Boston Transportation Planning Review, whereas the null situation is simply an extrapolation of existing urban activity location trends with no improvements in the transportation network.

Because the pilot study was experimental in nature, designed to provide information for a number of concerns, an additional element was added. This was conduct of the analysis at a more detailed level to determine if the accessibility results were sensitive to the degree of network aggregation. All 1980 analysis was done at an aggregate level of 104 districts (essentially cities and towns, with selected larger cities broken into smaller parts). The 1970 analysis was performed for the 104 districts and a disaggregate network consisting of 339 zones. Census tracts are the common denominator for both sets of network data, so the 339 zones can be summed into the 104 districts. The 1970 highway and transit networks—skim trees or interzonal and intrazonal (district) travel times—were developed at both the zonal and district levels.

Accessibility measures in terms of total study area population were developed for all combinations of functional activity type, mode, analysis year, and areal split (i.e., inner city and suburbs). In addition, for both the aggregate and disaggregate base case (1970) networks, accessibility measures were developed for several stratifications of the study area population. In particular, the population subgroups considered were population by age group, total households, households by income class, households by car ownership, total labor force, and labor force by employment type. Table 1 summarizes the data and tests conducted.

STUDY RESULTS

The computer software produces the modal travel times and urban activities data in an easily readable and efficient format. In addition to tabular output, the software produces frequency distributions and graphs of the accumulated percentages of population within 1-minute travel time intervals of each activity.

From the software output for the Boston tests it is possible to conduct the following types of analyses:

1. Accessibility conditions offered by alternative land use and transportation systems;
2. An intermodal comparison of accessibility levels offered by highway and transit networks;
3. The effects of network and zonal aggregation in the study; and
4. A more detailed analysis of existing accessibility conditions for subgroups of the population (e.g., different income, car ownership, labor force groups).

Moreover, it is possible to conduct each analysis in terms of inner, outer, and total SMSA areas. Each of these analyses was done with the Boston test data and documented in a report to DOT. Selected results are reported here.

Accessibility Conditions Offered by Alternative Land Use and Transportation Systems

Relatively small differences in accessibility between the existing conditions and the two future conditions are to be found in the study output with respect to the present and future highway networks (Fig. 1). This is due, in large part, to the fact that few additions were made to the highway network in the selected plan. The plan has a strong transit emphasis. Figures 2 and 3 show transit graphs of total population access to major employment centers from total and outer SMSA areas. The greatest impact of the planned transit improvements is in the outer SMSA, where transit extensions reduce travel times to major employment centers. These figures also indicate that transit accessibility deteriorates in the 1980 null network relative to the 1970 existing system. This deterioration is largely the result of a shift of residential location outward from the inner city over the 10-year period. Thus in the 1980 null network a larger proportion of the total study area population is located in the outer SMSA, where transit service is relatively poor.

Comparison of Highway With Transit Accessibility

Accessibility within the Boston SMSA by auto proved to be markedly superior to transit access for all of the activities examined in this SAA. Despite the presence of a relatively comprehensive existing transit system and the promise of even greater transit service in the future, each of the three networks—the 1970 base case, the 1980 null, and the 1980 selected plan—exhibited a similar pattern of auto dominance.

There are several reasons for the auto's comparative access advantage: the ubiquitous nature of its infrastructure, its minimal access requirements, and its higher average line-haul speeds. These are generally well-known facts. What is more interesting is the variation in the modal access differential by subarea (inner and outer SMSA) and by activity type. As can be seen in Figures 4 and 5, the access time differences (in this case shown for employment access) between the two modes are greatest in the outer SMSA area. This is because transit access in the outer SMSA deteriorates markedly from the level of transit service in the inner SMSA.

It should be noted that outer SMSA transit access is characterized by particularly

Table 1. Study elements.

Functional Activity	Mode	Time Period	Networks	Stratification
Employment	Transit	Base (1970)	Aggregate	S[a]
	Auto		Disaggregate	
		1980 Null	Aggregate	Population
		1980 Plan		
Medical facility	Transit	Base (1970)	Aggregate	S[a]
	Auto		Disaggregate	
		1980 Null		
		1980 Plan	Aggregate	Population
Airport	Transit	Base (1970)	Aggregate	S[a]
	Auto		Disaggregate	
		1980 Null		
		1980 Plan	Aggregate	Population
Recreational facility	Transit	Base (1970)	Aggregate	S[a]
	Auto		Disaggregate	
		1980 Null		
		1980 Plan	Aggregate	Population
CBD	Transit	Base (1970)	Aggregate	S[a]
	Auto		Disaggregate	
		1980 Null		
		1980 Plan	Aggregate	Population
Educational facility	Transit	Base (1970)	Aggregate	S[a]
	Auto		Disaggregate	
		1980 Null		
		1980 Plan	Aggregate	Population

[a]Population, population by age group, households, households by income group, households by car ownership, labor force, labor force by skill category.

Figure 1. Comparison of highway network accessibilities to major employment centers, total SMSA.

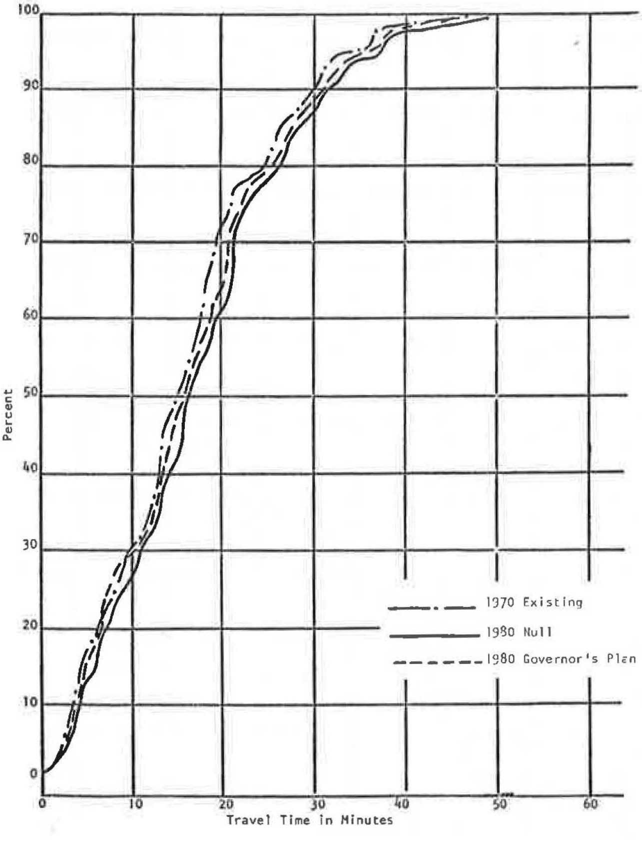


Figure 2. Comparison of transit network accessibilities to major employment centers, total SMSA.

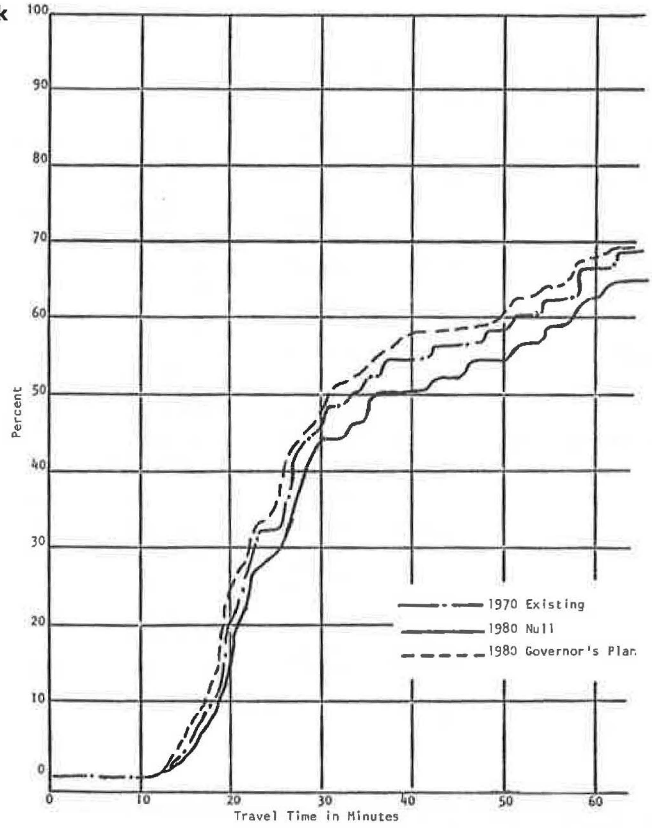


Figure 3. Comparison of transit network accessibilities to major employment centers, outer city.

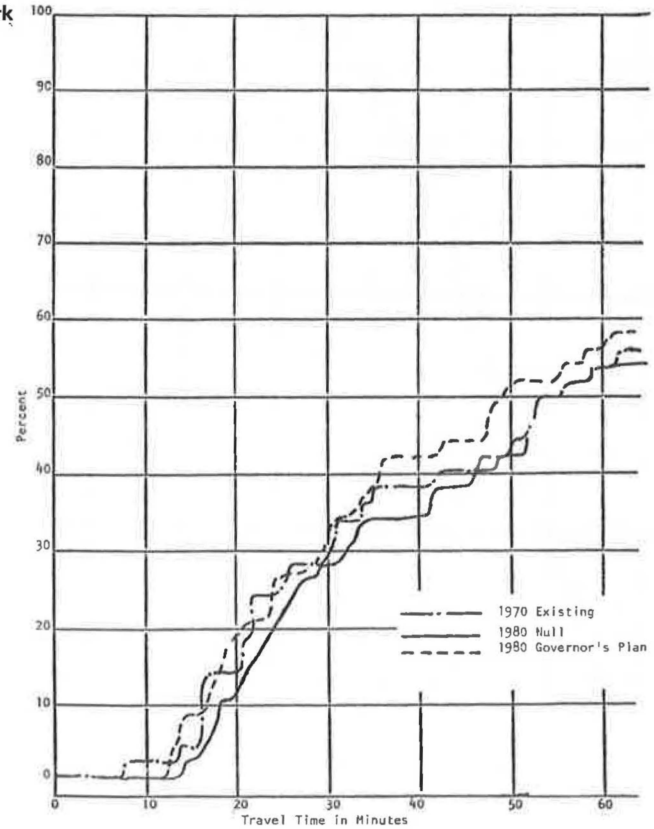


Figure 4. Comparison of modal accessibilities to major employment centers, 1970 existing system, outer city.

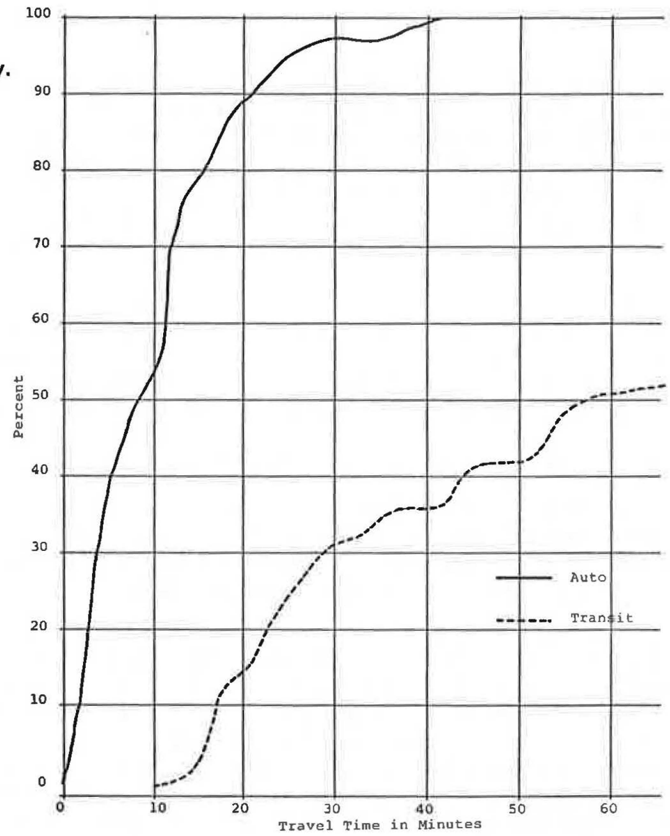
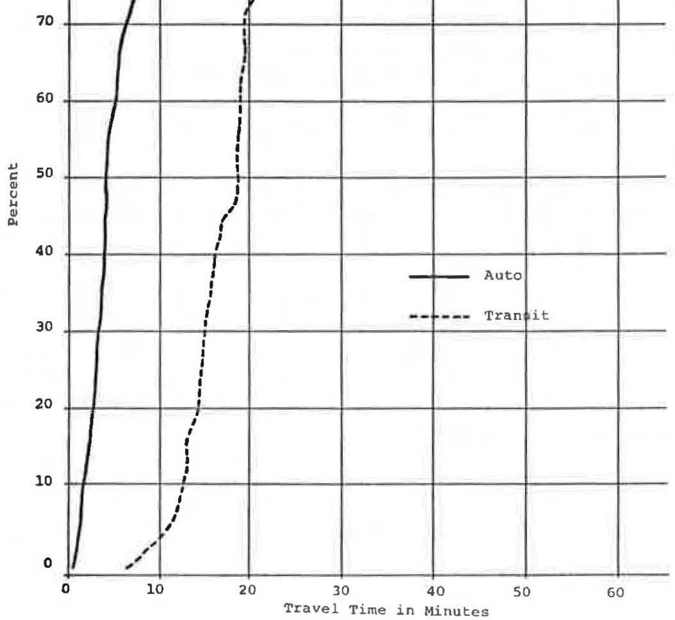


Figure 5. Comparison of modal accessibilities to major employment centers, 1970 existing system, inner city.



long access-to-station times and, in some cases, an outright lack of transit services in the outlying areas. The first characteristic is manifested by the small percentage of outer SMSA residents accessible to employment centers in short transit travel times; for example, the 20-minute transit travel time contour captures only 15.8 percent of the outer SMSA population compared to 71.6 percent of inner SMSA residents. And the lack of outlying area transit service is clearly shown by the 40 percent of outer SMSA residents who are inaccessible to a major employment center within travel times approaching $1\frac{1}{2}$ hours.

Although auto accessibility to employment centers is better for inner SMSA residents than for the population in the suburbs, the access time differences between the two areas are relatively small. The curves for employment access by auto rise steeply for both the inner and outer SMSA areas. The 20-minute auto travel time contour captures 100 percent of the inner SMSA population and 89.1 percent of the outer SMSA population.

Effects of Network and Zonal Aggregation

Figures 6 through 9 show the cumulative accessibility plots (on the entire SAA study area) from the aggregate and disaggregate analysis on four SAA activities: the CBD, airport, employment centers, and major recreational facilities. Examination of these plots reveals several interesting comparisons:

1. For three of the activities—airport, CBD, and employment—the disaggregate cumulative accessibility plot generally rises more steeply than the aggregate plot for both transit and auto. The reason for this is that in the disaggregate network the minimum interzonal travel time to these activities is lower than the closest district pairs in the aggregate analysis. Thus the disaggregate cumulative accessibility plots begin rising at lower travel times than corresponding aggregate network plots. For example, minimum transit access time to Boston's Logan Airport is 22 minutes in the aggregate network (from East Boston) and 15 minutes in the disaggregate network (also from East Boston).
2. Accessibility to major recreational facilities (Fig. 9) exhibits the opposite behavior: For both transit and auto, the aggregate cumulative accessibility plot rises more steeply than the corresponding disaggregate plot. In this case, the large number of major recreational facilities (44 out of the 104 aggregate network districts contained a major recreational facility) results in a large percentage of the population reaching a major recreational facility at the coded intradistrict travel times. In general, the intradistrict travel times are lower than the corresponding interzonal travel times of the disaggregate network.
3. The differences between the aggregate and disaggregate network cumulative accessibility plots can be quite large for both the transit and auto accessibility analyses. For example, the 10-minute auto time contour around major employment centers captured 80 percent of the population in the disaggregate network as compared to only 32 percent of the population in the aggregate network. Transit access exhibited marked differences between the two networks for airport access, where the 30-minute time contour captured 6 percent and 40 percent of the respective aggregate and disaggregate network populations.
4. As expected, the aggregate network cumulative accessibility plots exhibited a greater degree of "lumpiness" than the corresponding disaggregate cumulative plots.
5. There seemed to be no systematic difference between the cumulative accessibility plots from the two networks. The plots describing access to the CBD and recreational facilities were similar for the two networks. In contrast, aggregate and disaggregate analyses of airport and employment access differed markedly. It is difficult to trace the precise causes of the discrepancies between the two network analyses because the actual accessibility plots depend partly on the derived weighted skim tree times and partly on the actual distribution of population among zones in the disaggregate network comprising aggregate SAA districts.

Existing Accessibility Conditions for Subgroups of the Population

To gain a better understanding of the level of mobility afforded by Boston's existing

Figure 6. Cumulative accessibility for CBD.

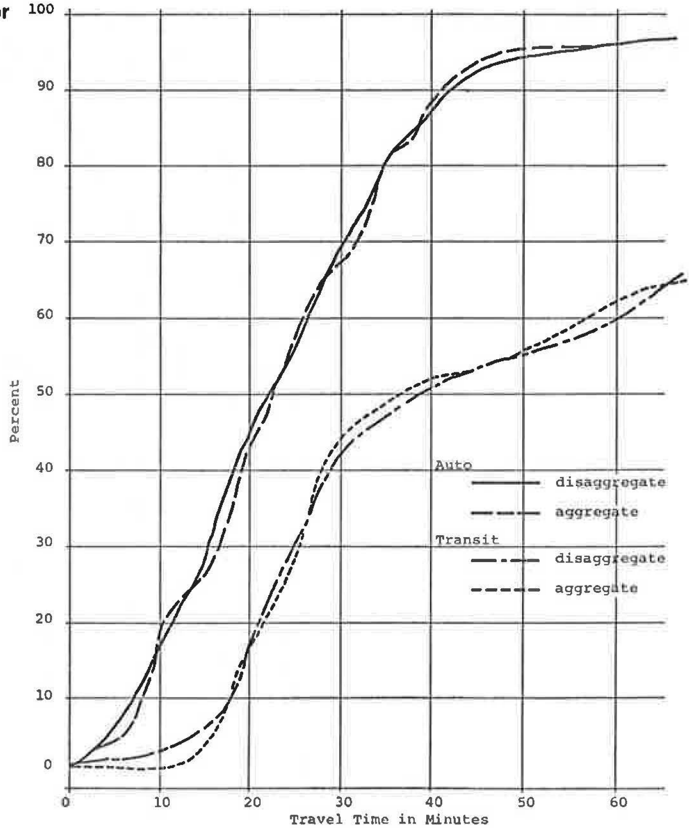


Figure 7. Cumulative accessibility for airport.

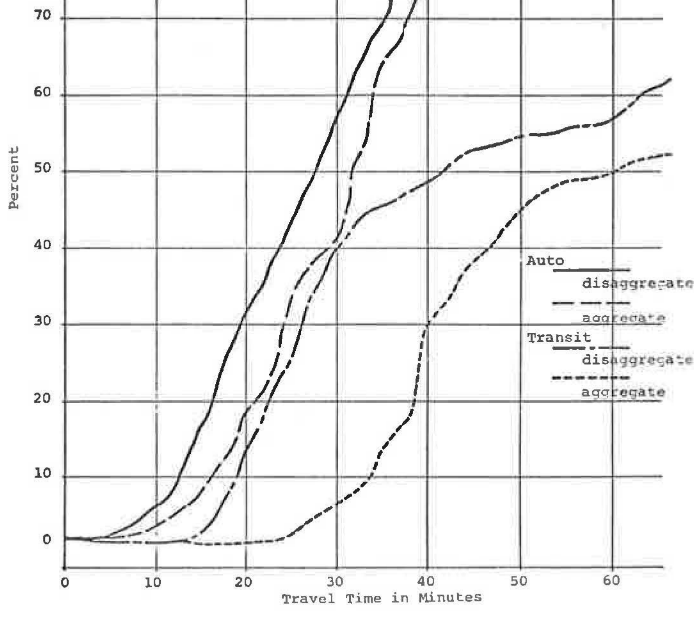


Figure 8. Cumulative accessibility for employment centers.

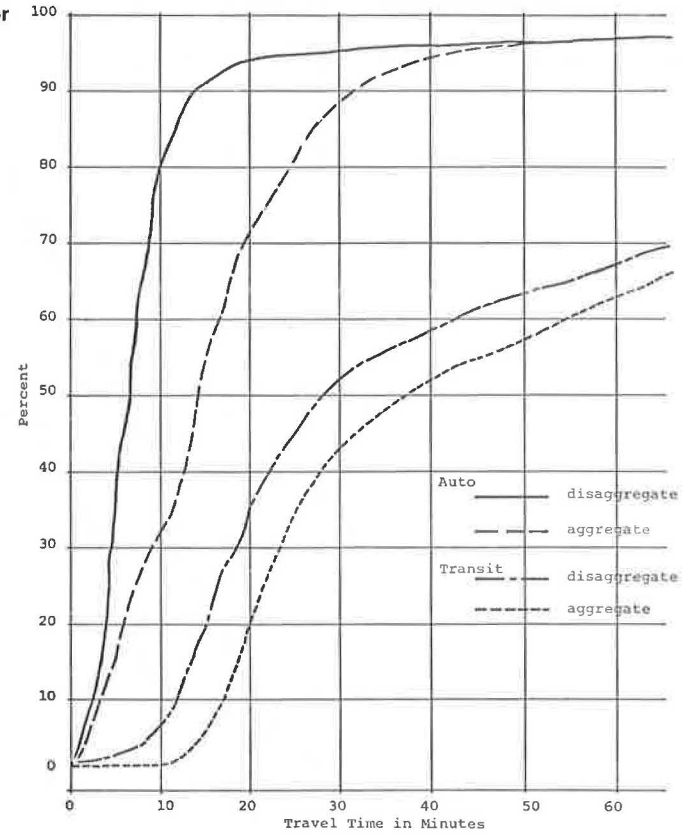
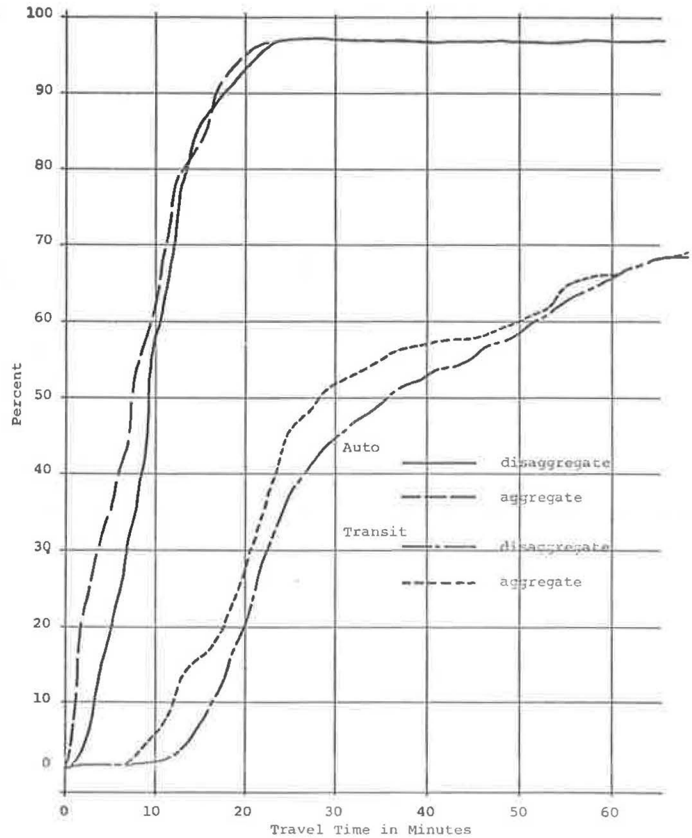


Figure 9. Cumulative accessibility for recreational facilities.



transportation system, given the spatial location of major activity centers and the characteristics of the resident population, this Special Area Analysis investigated the functional accessibility of specific population subgroups. In particular, access to each of the six major metropolitan activities was explored for four classifications of population: age group, income category, car ownership, and labor force skill category. Various income groups' access to major employment centers is reported here, analyzed at the district level.

Three income categories were employed in this SAA: low income ($0-$6,999), medium ($7,000-$9,999), and high income ($10,000 and over). The population was split into income classes according to zonal median incomes and within-zone income distribution. In the former classification, the entire population of each zone was considered to be in the low-, medium-, or high-income category depending on the median income of the zone. The latter classification apportioned the population of each zone among the three income categories in accordance with the intrazone distribution of household income.

Figures 10 and 11 show the transit and auto accessibility to the CBD using the within-zone income distribution classification. In each case, the low-income resident population appears to have the best access (i.e., the cumulative accessibility curve for low-income population lies above the curves for medium and high income) to the CBD. These access differences are most pronounced for transit travel to the CBD, where the 30-minute travel time contour captures 36 percent of the high-income population and 62 percent of the low-income population (Fig. 10).

The observed pattern of accessibility stratified by income category is not surprising in view of the characteristics and spatial location of Boston's resident population. Like most major U. S. cities, Boston's low-income population is concentrated in the city core and inner-city industrial towns. Median household income tends to rise with distance from the city core. This is clearly illustrated by the cumulative accessibility plots in Figures 12 and 13, where the population was stratified according to median zonal income. In this case, the difference between the percent of low- and high-income population accessible to the CBD for selected time intervals is as high as 95 percent.

The foregoing figures raise two other important points. First, the accessibility analyses for the two methods of determining population income stratification (i.e., according to zonal median incomes or within-zone income distribution) differed markedly. The classification scheme incorporating within-zone income distribution is clearly preferable to the zonal median population classification because the latter seriously overstates the quality of accessibility of the low-income population. This distortion was particularly manifest in Boston's SAA, where the zone size (and thus the within-zone income distribution) was relatively large.

A second point raised by the foregoing figures involves a caution on the interpretation of the cumulative accessibility plots. Although low-income residents appear to benefit from relatively good access to major metropolitan activity centers, it should not be concluded that an adequate level of transportation service necessarily exists for the economically disadvantaged. The apparent access advantage of low-income residents results primarily from their locational proximity to the CBD. However, in recent years there has been an increasing number of low-skill jobs locating in suburban areas and an increasing concentration of specialized, professional, and managerial jobs in the CBD. Thus, while the bulk of low-income (and presumably low-skill) population is within easy reach of the city core, they may be far removed from a growing source of low-skill employment in the suburbs. A necessary complement to the SAA is an investigation of the primary locations of employment and labor force by skill category. Ultimately, plans for upgrading urban transportation systems must be based on a detailed analysis of specific transportation corridors and the characteristics of activity centers and the resident population within these corridors.

CONCLUDING REMARKS

Regional accessibility, as measured by the percent of population within various travel time contours of significant regional activities by transit or auto, allows several types

Figure 10. Transit accessibility to CBD by income distribution.

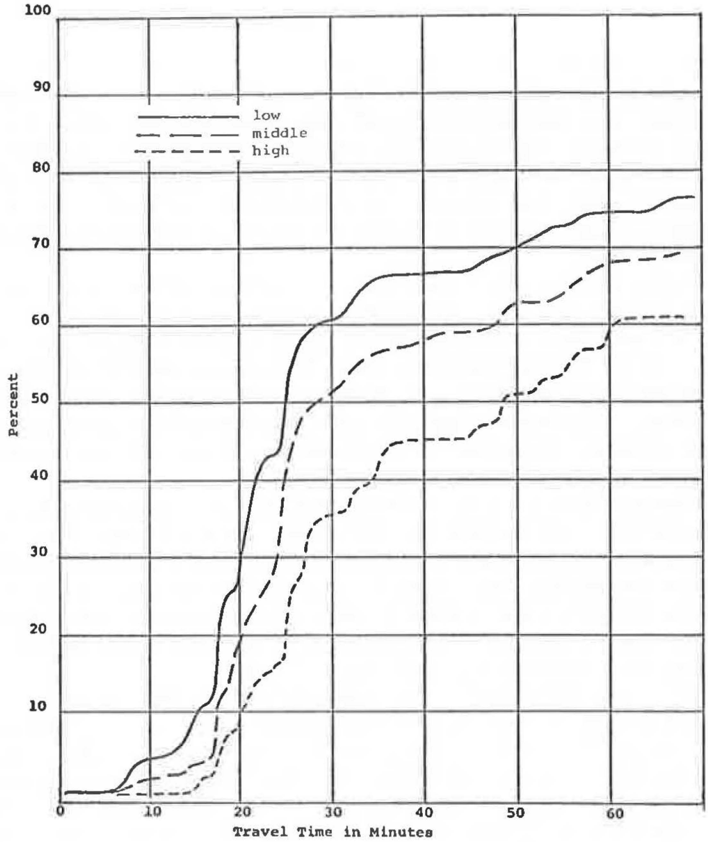


Figure 11. Automobile accessibility to CBD by income distribution.

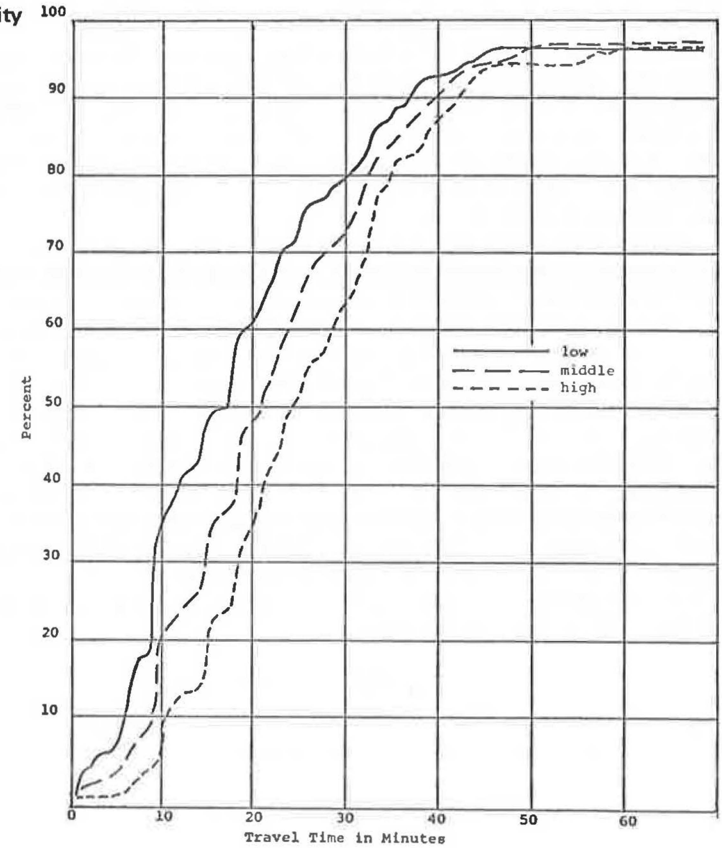


Figure 12. Transit accessibility to CBD by median income.

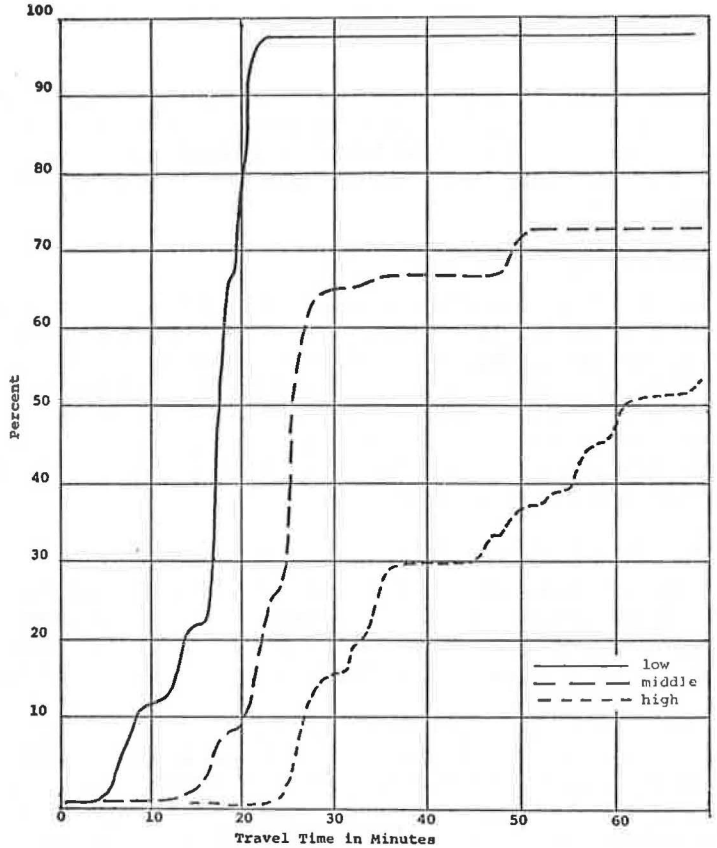
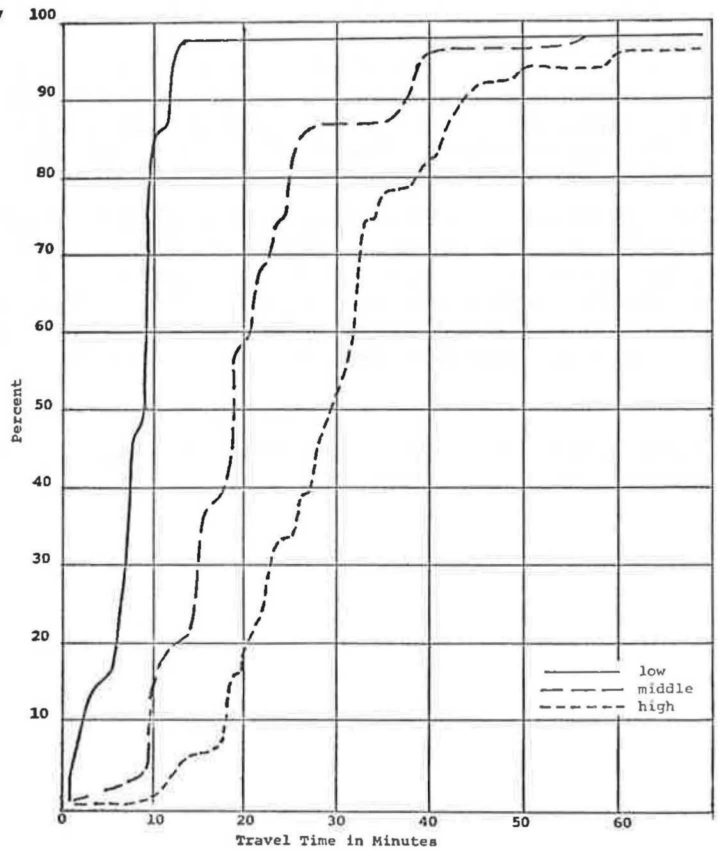


Figure 13. Automobile accessibility to CBD by median income.



of useful analyses to be made. First, a general picture of regional access conditions can be drawn. Second, some indication of goal achievement can be obtained if goals can be expressed in terms of the access measures. Third, plan comparisons can be made and related to costs to give some measures of relative cost-effectiveness in access terms.

Regional Access Conditions

Mean access travel time by mode, frequency distributions of percent of population within selected travel time intervals of major activities, and cumulative accessibility curves disaggregating inner from outer SMSA areas are all summary measures of regional access conditions. Because the measures encompass three elements—location of origin subjects, location of destination activity objects, and the connecting transportation system—they are of more use for evaluating area-wide plans than for evaluating each of the elements separately, even though it is possible to devise tests in which only one factor at a time is varied.

Cost-Effectiveness Analysis

If the accessibility measures are considered to be system outputs, they could be related to the various costs each system incurs and compared with each other in cost-effectiveness analyses of alternative plans. Cost would have to include transport system costs and costs associated with the land development or urban activities distribution pattern.

The importance of gaining an understanding of urban accessibility—particularly for low-income center-city residents—cannot be overestimated. Improving the quality of urban life requires not only the provision of employment, medical, educational, and recreational opportunities but also a convenient means of access to these facilities. Recent trends in urban land use and transportation supply have tended to exacerbate the lack of accessibility faced by urban dwellers. In the postwar period, we have witnessed

1. A marked suburbanization of urban services, especially employment opportunities;
2. A decline in the quality of public transportation service;
3. A generally sluggish response by public transportation authorities in establishing new routes geared to the emerging patterns of employment and residential locations; and
4. Constraints on the availability of housing for certain racial and low-income groups in the suburbs.

Taken together, these trends have led to an increasing degree of isolation for large numbers of our urban population. The issue then is this: If, relative to their ability to pay, large numbers of urban dwellers suffer excessive transportation costs in obtaining and maintaining employment and in reaching educational, recreational, and medical facilities, public action may be justified. The Special Area Analysis focuses on an analysis of this issue, both for present conditions and for future plans and programs.

REFERENCE

1. Final Manual: Special Area Analysis. Urban Planning Division, Federal Highway Administration, Aug. 1973.

INTEGRATING SYSTEM AND PROJECT PLANNING FOR EFFECTIVE STATEWIDE PROGRAMMING OF INVESTMENTS

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The need to address community and environmental issues in transportation planning has been widely recognized during the past few years. The initial response to these issues has been to include a broader segment of the public and to examine a wider range of impacts in the project planning process. However, a project-oriented approach has proved inadequate for a number of reasons. During system planning, decisions are made that determine many project-related social and environmental impacts, and there are some impacts that by their nature should be treated on a system basis (e.g., air quality, housing dislocations, land use). Uncertainty in funding levels, community preferences, and impacts, particularly during longer-range system studies, further complicate the ability of a planning process to address community and environmental concerns in a continuous manner throughout system and project studies. To address these issues requires planners to develop an approach to planning that provides for continuous coordination between system and project planning. A key to implementing such an approach is recognizing that during system studies attention can be focused on a range of project and system choices that are available, rather than limiting project studies to one set of potential projects. A key lever in implementing this approach is to require a system format that includes capital and non-capital options (policy and operating changes), and describes implementation strategies rather than end-state plans. Supporting such a format should be a documentation of ongoing system as well as project environmental studies.

• DURING the last few years there has been an unprecedented concern for community and environmental factors in all of the major areas of public decision-making. This has been reflected by, first, a very loud and vocal public dissatisfaction with proposed public works projects, followed by a great many federal and state legislative bills designed to improve the mechanisms for considering these factors.

In the highway planning profession, the historical response to this concern for community and environmental factors has been twofold: first, to examine a wider range of impacts for each individual project and, second, to include a broader segment of the public in the project planning process. Although these efforts aimed at the project level have represented a major and positive step forward in the highway planning field, there are several drawbacks to a project-oriented approach.

First, there are a great many community and environmental effects implied by a system plan that simply cannot be analyzed on a project-by-project basis and that can only be addressed during system planning. For example, impacts on land use or the regional economy and air pollution are examples of issues that can only be handled effectively on a system-wide basis.

Second, decisions that are made during system planning studies may significantly establish some of the social, economic, and environmental effects of a proposed project. For example, by the time a highway project reaches the location study phase

Publication of this paper sponsored by Committee on Transportation Programming, Planning, and Evaluation.

many significant decisions have already been made that may prematurely eliminate from further consideration other alternatives. The mode, type of facility (i.e., freeway, expressway, etc.), and general location have been determined by this time and a tentative schedule for implementation has been set. Different interest groups have often taken a strong position either for or against the facility, making further negotiations and compromise solutions difficult to achieve. Staffs doing location and design studies may therefore be constrained in their ability to take actions to alleviate or avoid adverse economic, social, and environmental effects because of system planning decisions.

Finally, by delaying community and environmental impact analysis until project studies are initiated, significant resources are expended for the design of projects that later are delayed, extensively revised, or even dropped from further study. Such changes in project concepts or schedules create the need to revise implementation programs and system plans. Although such delays or changes are not totally avoidable, anticipating project environmental impacts in system studies might result in fewer delays and disruptions to implementation programs.

In principle, these three factors suggest that there needs to be more continuity in addressing community and environmental issues throughout the entire planning process from system planning through detailed project design. In practice, there are several reasons why many significant social, environmental, and economic effects are difficult to anticipate during system planning studies.

The purpose of this paper is to discuss the problem of integrating system and project planning to systematically include community and environmental concerns. The paper will first identify the major problems in the current system-project relationship, then discuss a philosophy for integrating the activities at these different levels of planning, and finally present some practical and implementable techniques for more effectively integrating system and project plans.

DEFINITION OF SYSTEM AND PROJECT PLANNING

Before discussing the issues involved in relating system and project studies we first must define the terms as they will be used throughout the discussion. Naturally, any definition of system and project planning is somewhat arbitrary and it will vary from organization to organization. Both activities, however, are part of an overall process through which an agency manages resources and provides transportation and related services.

By <u>system plans</u> we refer to the sum of the facility, operating, and policy changes proposed over time for a particular geographic region. [This definition of system plan is obviously more than a map displaying proposed major capital improvements. The usefulness of this definition in integrating project and system studies will be discussed in more detail in a later section.] Thus there can be system plans for either a state, a region, or a municipality. Plans for different governmental (or geographic) levels will be overlapping and highly interdependent, however, and consistency among the different transportation system levels must be a primary objective of the overall planning process.

The <u>system planning process</u> encompasses all those elements and activities necessary for producing area-wide plans. This definition of the process is broader than the usual definition because it includes the institutional structure and decision-making process for transportation (including the various interest groups involved), the process for generating and allocating funds, and the technical and non-technical procedures used by the planning or implementation agency. Defined in this manner, system planning encompasses a broad range of components and provides a framework within which project-related decisions can be carried out.

<u>Project planning</u> involves those activities that prepare some component of the system plan (whether a highway link, transit link, or traffic operations scheme) for detailed design and implementation, explicitly recognizing the relationship between a particular component or "project" and the entire system plan; i.e., in most cases, whether a project gets built or not can have major implications in the operation of the rest of the system.

THE PROBLEM: ISSUES IN INTERRELATING SYSTEM AND PROJECT PLANNING

Traditionally, system planning and project planning have been viewed as sequential activities, with system studies describing a general network and project studies preparing detailed designs for particular links. Although the two activities have not been entirely divorced from each other, system plans have specified the total list of projects that could be considered without providing strong guidance for the scheduling and implementation of specific projects (i.e., priority-setting and programming).

The gulf that can exist between planning at these two levels if carried out in this way can be characterized in a number of ways. First, the time horizon for the two activities has been very different, with system studies focusing anywhere from 20 to 30 years in the future and project activities looking 1 to 10 years away, depending on the project scope and lead time.

Second, the geographic area of concern to system planners is generally an entire urban area, a regional planning district, or the whole state, while project planners focus on a single (and often narrowly defined) corridor.

Finally, the personnel involved in the two activities often have very different perspectives on transportation problems. At the system level, area-wide issues are addressed, the emphasis is on planning rather than engineering, and considerable coordination is required with other agencies involved in types of development other than transportation. At the project level, more detailed design work is emphasized, and engineering location and design play a dominant role. Even more important than the difference in disciplines is the fact that the system and project studies are generally carried out in different units within an agency, with resulting problems in communication caused merely by physical separation. This is particularly true in the case of highway and transit planning. Often one agency is responsible for multimodal system planning, but project planning and implementation invariably occur in different agencies. In most cases the state is responsible for highway implementation and local or regional operators are responsible for transit.

The current gap between system and project planning can be described, at least partially, therefore, by a difference in the time horizon, the geographic area of concern, and the personnel involved. To overcome this "clash of cultures" a number of issues must be addressed at both levels of planning.

Barriers to Integration: System Issues

There are a number of problems with system planning that impede effective integration with project studies (1):

1. Many impacts of system decisions are long-term, occurring 10 or 20 years in the future. The effect of system decisions on location and development patterns and the future demand for transportation are examples of long-run impacts.
2. Many system impacts are area-wide and cannot be handled on a project basis. Air pollution and housing dislocation are impacts that ought to be handled by an area-wide rather than project-oriented approach.
3. The system impacts are difficult to predict because of a lack of understanding of complex cause-and-effect relationships. The best example might be the long-disputed relationship between transportation and land use patterns.
4. Some impacts are not fixed until project planning has determined the specific location and perhaps even design of a proposed facility. Thus at the system level it would often be difficult or impossible to really treat such impacts except in terms of general estimates or likely ranges of related impacts.
5. Environmental and social issues have been given little if any attention in system planning. They are essentially only carried out during project studies, where the impacts and issues are clearer and can be treated in detail. This approach ignores area-wide environmental effects and postpones the identification and analysis of project impacts, minimizing their influence on technical studies during both system and project studies. The result is that significant resources are often being spent for the detailed

design of undesirable or unacceptable projects. The need for a systematic and continuous treatment of community and environmental impacts is perhaps the first and foremost reason for improving the integration of system and project planning.

The full range of multimodal alternatives (both facility and policy changes) has not been considered in most system planning studies. Yet, as project studies progress, questions are raised about other options that, if approved, would have severe implications for, and require significant revision of, the entire system plan. In many cases, naturally, funding constraints inhibit a search for a wide range of alternatives by making funds available for only particular model solutions. A general relaxation of these funding constraints is occurring with the current change in the use of the Highway Trust Fund. This relaxation of funding constraints is making the examination of a range of transportation alternatives more meaningful.

6. The technical procedures used in system planning tend to impede the examination of many alternatives. For example, functional classification and needs studies generally assume a "desired" or "minimum tolerable" level of service. However, once a level of service has been assumed, the appropriate design standards of a road are set. By examining service characteristics alone in making preliminary decisions on the types of facilities needed or desired, system planning is ignoring critical social and environmental issues as well as prematurely limiting the range of alternatives under study.

The network flow modeling tools have been oriented toward the analysis of a single mode without evaluating the relationships among modes. In addition, the models reflect an emphasis on aggregate area-wide effects and contain built-in biases that make examination of disaggregate needs and impacts difficult.

For example, existing techniques often assume that total demand is independent of the existing level of service or the level of service to be supplied in the future. In assigning trips to links, capacity limitations sometimes are also ignored. Such techniques result in unrealistic demands and tend to bias evaluation toward favoring more and larger facilities without examining the full range of consequences of such a policy.

7. Evaluation techniques have tended to emphasize average area-wide benefits, with little examination of the incidence of impacts and the specific requirements of subareas and subgroups. Such aggregate measures tend to conceal the distribution of benefits and costs among different user groups (local versus through traffic, various income groups, etc.) or between users and non-users. More attention must be paid to the measurement and prediction of the incidence of impacts.

8. Goals and objectives have emphasized economic efficiency in a narrow sense and have not been useful in illuminating the trade-offs that can occur among different interests. In reality, many communities contain a diversity of views about transportation. System planning must now also strive for broad public participation to determine the objectives of various groups by providing a forum within which compromises can be made.

9. System plans have been advisory in nature with little influence over actual programming decisions. In fact, given the revenues expected over the planning horizon, system plans have often represented unrealistic target networks. Often system connectivity and completion of the master plan are used to partially justify particular projects, even when completion of the network on schedule seems unlikely due to resource or community considerations. Many states are now in fact recognizing that they may never complete their master plan.

10. Uncertainties in predicted revenues, demand, impacts, or community acceptability have been ignored. Often the nature and magnitude of these uncertainties have not become apparent until a strong commitment has already been made to particular components of the plan. For example, the patterns of land use and economic activity assumed during system studies may be very different from those existing when a particular project is ready for construction. Similarly, developments in new technologies and new funding patterns may allow new modes or different mixes of modes. System plans may have to be significantly revised to exploit such new opportunities or information.

Project Issues

At the project level there is a similar set of problems that also act against a closer integration with system studies:

1. Independence of projects in an implementation program is often assumed, with even different segments of the same route being studied separately in some cases. As a result, project designs implicitly assume completion of the target network by the specified horizon year, with little consideration given to other design scales. In many cases this is an extremely inappropriate and costly assumption. If the target network is not completed, or not completed on schedule, better area-wide service could often be achieved with smaller scales. Also, allowing variations in project scale makes the possibility of meeting social and environmental goals more likely. A second result is that area-wide impacts of specific projects are difficult to deal with or are ignored and deemphasized.

Often rural projects are treated on a project-by-project basis. Many states view system planning as predominantly an urban activity, with the "3C" process serving as the legal impetus for developing a structured urban system planning process. Integrating system and project planning is in fact a rural as well as an urban problem. In rural areas there is a definite need to coordinate all project studies in a strategy for improving the rural transportation system and to solicit the involvement of interested groups early in the planning process. Furthermore, on a statewide basis, there is a need to coordinate all funding and programming decisions. Treating urban and rural projects separately may not result in the most effective allocation of funds and improvements to the statewide transportation system.

2. System level evaluation criteria are often used when the issues of most concern are local and disaggregate. For example, the benefits for peak-period through traffic might be the major justification given for a project, whereas the issues of concern for the local community are disruption to local traffic patterns or off-peak accessibility to shopping centers.

3. System plan revision is not seen as a viable option. Project delays or cancellation often do not result in a review and revision of system plans or at the very least make such a review a cumbersome task. Dropping a small and isolated project from further study might have few system implications and not warrant revising the system plan. However, when a large project or a number of projects are delayed or dropped, there is a need to critically reexamine the allocation of resources to other projects in a program and to determine whether a revision in the system plan or program is desirable.

While state highway and transportation agencies are beginning to recognize and address some of these issues, further steps can and should be taken. Any philosophy and techniques for integrating system and project planning must recognize the need to address both area-wide and local issues throughout the process and specifically to deal with the problems identified above at both the system and project planning levels.

Some researchers have described the current situation as one where at the system level decisions are often uncontroversial, yet most of the efforts at developing technical models and tools have addressed the "system problem" (2). At the project level, decisions tend to be much more controversial, yet few if any techniques and procedures have been developed to address the issues of concern. Again, the basic problem involved in integrating planning at the two levels is to strike a balance between the concern for systematic service requirements and localized disaggregate requirements. This leads us to present an outline of a philosophy that can lead to narrowing the gap between system and project planning.

A PHILOSOPHY FOR INTEGRATING SYSTEM AND PROJECT PLANNING

To effectively address community and environmental factors throughout the planning process will require new technical procedures as well as an improved integration of system and project planning. Although some states have taken steps to strengthen the relationship between these activities, traditional practice has not yet accomplished the type of ongoing integration of system and project planning proposed here.

The traditional philosophy of integration has largely been that system planning preceded project planning and that project planning developed projects necessary to implement a "master plan." While the master plan gives a precise picture of what the future transportation system might be, it has not been tied explicitly to the programming activities that determine how projects will be scheduled toward implementation of the plan. Since implementation strategies are not considered in system planning, the master plan often represents an unrealistic goal that in turn distorts near-term project decisions if completion of the plan (or completion on time) is assumed.

More importantly, by prematurely focusing on only one future system, the master planning approach loses flexibility to revise plans in the future. The implementation program is geared toward the construction of one target-year plan. When community and environmental impacts become known during project studies, it is both technically and psychologically difficult to respond and consider new project or system concepts. By not anticipating a range of designs for, or the potential deletion of, a particular link during system studies, large amounts of resources are required to revise the plans later.

In fact uncertainties in funding, community preferences, and impacts of a particular action place severe limitations on a master plan approach (3). Transportation options must be developed with the knowledge that today's decisions are based on an imperfect understanding of the future of a region. Unforeseen changes may require new responses and adaptations that are impossible to fully evaluate at the present time.

The really important decisions are the near-term programming choices that irrevocably commit resources to projects and studies. In system planning it is neither desirable nor necessary to make firm decisions on one target system in some future year. By leaving future decisions open until more information is obtained, system planning can take into account possible future options and events and help to evaluate the most flexible direction for present programming decisions.

Many of the problems currently facing transportation agencies are directly related to the inability of the present system planning process to explicitly deal with uncertainty and to effectively relate near-term programming decisions to longer-range system plans. Therefore, one of the first and foremost changes in system planning is that system planning must focus not only on desirable master plans but on implementation strategies as well.

The philosophy for interrelating system and project planning must see those activities not as sequential but as integrated in a continuing manner. System planning should not precede project planning but provides a framework within which project decisions can be made and serves to mediate between and coordinate all the ongoing project studies. System planning thus should periodically assign resources and priorities among the ongoing subarea studies and project planning processes. The results of project planning influence decisions about the overall system, not just vice versa. Because project studies influence system planning, they must be coordinated with system planning in an ongoing way.

Such a philosophy explicitly recognizes that transportation plans are not implemented instantaneously in "one shot" but rather in a series of staged increments. System planning, therefore, ought to examine a range of different implementation strategies. For example, the 20-year time horizon for a master plan might be divided into 5-year stages. Each stage of a particular implementation strategy might include construction of a number of highway links or transit options and operating and policy changes, as well as different studies.

By developing different sequences of actions on facility improvements, emphasis is placed on what choices are available over the planning time horizon and how present decisions affect the range of choices available in the future. The different sequences can explicitly recognize uncertainty by evaluating the impacts of a number of potential outcomes from project negotiations or impact studies. Thus, implementation strategies provide a convenient framework for relating system and project planning by focusing on both short-term decisions and longer-range plans.

Although the resources available for system planning will restrict the number of sequences and uncertainties that can be considered, attention need not be limited to one sequence over time. In theory, implementation strategies could be developed for every possible event that may occur in the future. In practice, however, because of the complexity and number of future events and options, they need only represent what appear today to be major choices facing the decision-making process.

The role of system planning in the context of alternative implementation programs is to carefully anticipate the choice issues that must be resolved as planning continues and devise tentative sequences of improvements based on potential outcomes from these choices. As new information is gathered, new options will be added, while others will be dropped from consideration.

In summary, system and project planning must be integrated so that the go/no-go decision to implement any project or a particular design will not disrupt the ability to allocate funds smoothly to other high-priority projects.

Obviously, both the master plan and a plan based on implementation strategies can be altered in future periods in response to changes. Neither irrevocably commits a region to one sequence of implementations over time. The two essential differences between the approaches are how initial decisions are made and the flexibility provided to revise the plan over time. Initial decisions with the master plan aim at one target-year system. Although the master plan in fact can be and in practice is revised, many alternatives are foreclosed prematurely by focusing initially on one target network. Recognizing that revision will occur later may in fact lead to an entirely different concept of a master plan and a more flexible and adaptable first-period set of decisions. The implementation strategy approach therefore considers uncertainty explicitly and a number of potential improvement sequences when initial decisions are made. By anticipating the changes that may occur and a range of the choices available in the future, this approach explicitly requires periodic evaluations and revisions and ongoing coordination with project studies.

TECHNIQUES FOR INTEGRATION

The implications of implementing a philosophy of continuous integration of system and project planning extend to all aspects of the current system planning process. Improving the current process could involve as drastic a move as changing the institutional relationships between state, regional, and local levels of government or changing the allocation process for the distribution of transportation funds. It most certainly will involve changing the activities of the planning agency, including needs and sufficiency studies, network flow modeling, and priority setting and programming.

This section identifies a number of specific techniques for improving the system and project planning interface by changing the documentation requirements to support a continuous planning process. [Other techniques dealing with legal, administrative, and technical changes that would improve the integration of system and project planning are discussed elsewhere (4).] These reporting requirements represent a key activity of a planning agency, and they can be designed to provide an effective integrating mechanism for project and system planning.

System Plan Format and Content

One of the best opportunities for more effectively integrating system and project planning lies in strengthening the ties that exist between system planning and the programming process that focuses on near-term implementation of sets of projects or programs. There are a number of reasons why programming is a key activity. First, the programming process is the focus for important decisions and negotiations concerning the commitment of money and manpower to various projects and studies. Second, programming provides an appropriate forum for consideration of both long-run and short-run actions aimed toward implementation of a system plan. Finally, programming is a periodic activity (often with yearly budgeting cycles) and thus is a convenient checkpoint to review the status of ongoing project studies and to revise the system plan in light of current project development activities.

Traditionally, the link between system planning and programming has been weak. System planning primarily through functional classification and needs studies provides lists of projects that are then assigned a priority in some manner. Programming then chooses projects until the budget is exhausted, subject to a number of other constraints. A key lever to strengthen this linkage is to require a system plan format that encourages discussion and documentation of both system and project activities and provides for stronger and different kinds of system inputs.

The basic planning document should be a multiyear program package that combines both short-term and longer-run improvements while explicitly recognizing the resource and other constraints facing transportation plans in the system plan development phase. Such a document would represent an extension of the current multiyear implementation programs developed by most state highway agencies to cover the entire planning period.

Currently most states require a 20-year target plan and a short-range (up to 5 years) implementation program. Our recommendation is to combine the requirements for the target-year transportation plan and the implementation program into one planning program package that reflects reasonable resource assumptions and illustrates all the actions on transportation anticipated for an area over the entire planning horizon. Thus, the proposed planning document would contain all capital improvement projects (large and small), maintenance, operating, policy changes, and studies for all modes within a region. In addition, the planning program should identify all sources of revenues and the implementing or operating agency responsible for each action contained in the program.

For urban areas such a document would extend the U.S. Department of Transportation requirement for a unified work program to include project implementation (such as UMTA capital and service improvements) as well as planning activities. Moreover, it is recommended that the planning program format be adapted for both urban and rural areas.

Also, a number of options for many projects should be included in the list of projects to be assigned a priority, since each option for a particular facility has a different set of impacts, a different cost, and a different effect on the community. As shown in a previous paper by two of the authors (3), the effect of a budget constraint alone can alter the set of projects chosen. For example, it may be desirable to select something smaller than the largest of all options for each location if the budget is tight and overall network coverage and equalized mobility is an objective. By providing multiple alternatives, we may increase the cost of studies but we will have also increased the flexibility for change in later periods.

There are a number of advantages to defining the basic planning document as a multiyear planning program rather than a target-year plan. First, defining the system plan as a planning program encourages the planning agency (or agencies) to immediately focus on resource and other constraints early in the planning process. The result will be a plan that represents a proposal with a realistic potential for implementation and hence a better guide for transportation decision-making. In the past, system plans have often described only "desirable" target networks that have had little influence on and relationship to programming and implementation decisions. Although the content of the plan can be expected to change at any time, the plan should reflect as realistically as possible existing or anticipated constraints on transportation decisions (resource, environmental, etc.).

Second, combining short-run and long-range improvements in a program package increases the potential for the effective involvement of a wide range of different interest groups, particularly in system planning. Program packages define both immediately implementable steps (such as signalization, flow metering, minor upgrading of existing facilities and interchanges) and the longer-range improvements (such as major new facilities and broad policy changes like peripheral parking schemes, or even new studies). Since the lead time for major transportation projects can be as long as 10 years, program packages show interest groups how their concerns can be addressed in the near future as well as give all participants a realistic sense of the time required for more major improvements. A number of states have recognized this already, at least in a preliminary way. The Connecticut Department of Transportation, for example, has adopted a similar format and uses regional plan summaries as the basis for conducting public meetings in each planning region of the state.

In addition, public participation should not simply be involved in deciding on the studies and projects to be included in the plan but also on the relative priority of those studies and projects. The proposed plan format will focus on both the content and scheduling of planning activities.

Finally, defining the plan as suggested here will make it easier to relate and coordinate system and project planning in an ongoing manner. Since the desirability of some projects in a region, or their timing, may depend on other projects in the plan due to traffic or resource considerations, the program package can explicitly identify these interdependencies and indicate when or how changes ought to be made to the program package if the status of a particular project changes. In programming and project development, a project often is considered independent, for the most part, from other projects under study. Using a planning program format will facilitate the inclusion of system considerations in project development decisions. Also, combining plans and programs for all modes will encourage cooperation among agencies doing system planning and those responsible for implementation.

Contingency plans may provide additional flexibility within the basic planning program format, particularly in areas where a number of controversial issues are unresolved or for major projects with significant lead times. In these cases, in order to facilitate the orderly allocation of resources, it may be desirable to develop tentative implementation strategies for a range of potential future decisions. For example, if a major freeway has a 10-year lead time but no assurance of its acceptability can be made that far in advance, it may be wise to examine and plan a contingency program for smaller-scale and traffic operations improvements in the corridor in case at some future point in corridor studies or project development the freeway is dropped. By anticipating such occurrences, the agency can provide for an orderly implementation program rather than reacting to crises as they occur. At the same time, the agency can provide the community with more than a "freeway or no improvement" choice.

Although developing contingency plans may require more resources for planning, it provides for a more realistic range of network and project choices when there is significant uncertainty in funding levels, community acceptability, the predicted impacts of proposed projects, and external events with implications for transportation (land-use control, federal or state air quality regulations, etc.). In the long run, contingency plans may result in a more efficient use of resources by providing flexibility and keeping options open.

While alternative plans can be displayed particularly for the medium to long run, the first 1 to 2 years of the planning program should be decisive and represent what actually will be budgeted and implemented or studied during that time period. By making the first few years of the program decisive but explicitly recognizing the range of choices available in subsequent time periods, the planning document can support and indeed encourage a periodic decision-making process. Every 1 or 2 years a new budget is prepared and the entire planning program is documented. The proposed format then encourages a planning process whose periodic output is a new budget that reflects the fiscal flows over time anticipated in the planning program. Such a document and reporting strategy provides one means for addressing the relationship between project and system planning in a continuous manner as required by the process guidelines contained in FHWA Policy and Procedural Memorandum 90-4 (required by the Federal-Aid Highway Act of 1970).

System Environmental Report Associated With a Multiyear Planning Program

There is widespread agreement that social and environmental impacts ought to be considered in system as well as project plans. There is considerably less agreement on the appropriate mechanisms and techniques for accomplishing an integrated approach to environmental analysis throughout the planning process.

One possible mechanism is to encourage explicit documentation of the social and environmental impacts of system plans through preparation of a system environmental report, which ought to be integrated into the system plan implementation program described in the previous section. The California State Transportation Board has developed guidelines for the preparation of regional plans that require such a document (5). Pennsylvania's Action Plan also calls for an "environmental overview statement" during system planning (6).

A system environmental report (SER) should neither approach the detail currently found in project environmental impact statements nor simply summarize the current status of project environmental analysis. Rather, the SER should present a summary of the plan's area-wide implications for, and impacts on, the environment as well as provide a framework within which later and more detailed project environmental analyses can occur.

Specifically, the SER might contain the following:

1. Identification (and possibly map overlays) of environmentally sensitive areas, land use assumptions, prevailing air and noise pollution contours, and general topography. Also included would be basic demographic data and projections on population, income levels, and employment and the range of uncertainty associated with these projections.
2. A summary of aggregate area-wide social and environmental effects implied by each of the system plan alternatives under consideration. Such a summary would estimate such things as the total open space and farm land likely to be taken or subsequently developed, the area-wide effect of displacements from all projects on the housing market, and the compensation programs required to attempt to minimize adverse effects.
3. Identification of unresolved issues or further studies required in order to estimate the system-wide social and environmental effects.
4. Identification of the status of environmental studies for each project, including major unresolved issues, network implications (i.e., interdependencies with other projects) for projects currently being seriously questioned on environmental grounds, and the current status of the project EIS (under way, completed, approved, etc.).

It is to be hoped that the SER could be produced as a natural by-product of the planning process and the reporting that had occurred to date. Given the magnitude and complexity of issues to be addressed in the SER, it is extremely important that its production not entail a massive after-the-fact documentation exercise. Rather, the SER should be designed to merely summarize or compile the results of ongoing analysis and thereby avoid the criticism leveled at project EISs: that documentation often does not occur early enough in project development to affect the study, in addition to being a burdensome and time-consuming task.

For example, in states where the priority-setting process of choosing projects for an implementation program is done in an open forum considering both technical and nontechnical factors, that portion of the transcript of such a meeting or series of meetings relating to social and environmental issues could be summarized or placed verbatim in the SER.

The actual documentation of system environmental concerns ought to be integrated with the documentation of the system plan itself. Thus, if the plan takes the form of a multiyear implementation stretegy as recommended in the previous section, the SER sections of that plan ought to discuss the anticipated impacts of alternative sequences of improvements and what sequences are left open or foreclosed by the first-period budget decisions. As the system plan is periodically reviewed and updated, the SER component of the plan should also be reviewed and revised.

SUMMARY

In conclusion, there are a number of issues that must be addressed in both system and project planning before close integration of these activities and more effective investment decision-making can occur. These issues include the need for a continuous and systematic appraisal of social and environmental concerns at all levels of planning and the need for plans and programs to explicitly recognize the uncertainty in any long-run predictions or tentative decisions.

To respond to these issues, we recommend a philosophy for coordinating system and project planning on a continuous basis. This philosophy suggests the need for system planning to focus on implementation and investment strategies as well as master plans.

The documentation of the planning process should support the recommended approach. First, a plan format that combines a target-year plan and implementation program in a multiyear and multimodal program package will encourage coordination and display both short- and long-run options. Second, a requirement for a system environmental report product as a management and decision-making document can help to ensure early consideration of social and environmental concern. Such a document should present a summary of area-wide effects and identify issues to be resolved in project studies.

Both the system plan and environmental reporting strategy should be designed to recognize that the most important decisions are the near-term programming and budgeting decisions. The system plan and environmental report should display the consequences of the resource allocation decisions in terms of the options left open and foreclosed and the likely ranges of impacts. In addition, any documentation should lend itself to periodic review and revision without necessarily requiring major new reporting efforts.

REFERENCES

1. Kinstlinger, J. Relationship of Urban Transportation Planning to Area-Wide, Subarea and Project Planning. Paper presented to Objectives Task Force of the AASHO Subcommittee on Urban Affairs and Socio-Economic Factors.
2. Wachs, M., Hudson, B. M., and Schofer, J. L. Integrating Localized and System-Wide Objectives in Transportation Planning. School of Architecture and Urban Planning, Univ. of California, Los Angeles, Jan. 1973.
3. Neumann, L. A., and Pecknold, W. M. Application of the Time-Staged Strategic Approach to System Planning. Highway Research Record 435, 1973, pp. 20-31.
4. Reno, A., Schneidman, B., and Manheim, M. Opportunities to Improve the Interrelationship of Urban System and Project Planning. Urban Systems Laboratory, Massachusetts Institute of Technology, Rept. 73-1, Sept. 1973.
5. Regional Transportation Plans: Guidelines. California State Transportation Board, Sacramento, April 1973.
6. Action Plan. Pennsylvania Department of Transportation.

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