PREDICTING PARK-AND-RIDE PARKING DEMAND

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This study is concerned with the determination of design criteria for prediction of parking demand at park-and-ride facilities in medium-to-large cities in the United States. Ninety-three change-of-mode parking facilities in 10 cities were used in the study. Data were collected through a mail survey. The report includes an analysis of important physical, operational, and locational characteristics of change-of-mode parking facilities experienced by 26 agencies operating 73 rail and 20 bus facilities. The change-of-mode demand is estimated through a prediction equation developed by linear regression analysis. The prediction model was tested for its applicability by using separately supplied data from a committee of the Institute of Traffic Engineers. Input to the model consists mainly of characteristics of the city, the transit system, and the location of the parking facility.

TRANSPORTATION engineers, who have insight into the urban dilemma, have long advocated the design of a coordinated and integrated system. A system that utilizes each different transportation mode where it is most efficient and that provides for a smooth connection among the modes qualifies as a coordinated transportation system. Change-of-mode parking facilities, also known as park-and-ride lots, perform the role of a connecting link between passenger car and transit. The passenger car is used in the collection of the trips in areas of low-density trip ends. At the same time, by increasing the service area of transit stations, change-of-mode parking increases the demand for transit along established travel corridors. Finally, by diverting such demand to locations of lower land use density and lower land value, change-of-mode parking reduces the demand for parking in downtown areas.

PURPOSE AND SCOPE

There were 2 objectives of the study. One objective was to statistically analyze the effect of the physical, operational, and location characteristics of change-of-mode parking facilities on their usage (percentage of lot occupancy). Factors such as the adequacy of the transit system and the metropolitan area characteristics were also included in the analysis.

The second objective was to predict the demand for change of mode. That was achieved by developing a multiple linear regression equation whose independent terms are a measure of the physical, operational, and location characteristics of the parking facilities. An acceptable prediction equation must possess a logical sensitivity, satisfy all statistical constraints, and be easily applied.

DATA COLLECTION

The data collection method was constrained by a limited budget. Therefore, it was necessary to rely on data already collected or easily provided by change-of-mode operators. For that reason, it was decided that a questionnaire should be sent to change-of-mode operators.

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Questionnaire

The change-of-mode demand and a variation therefrom are the dependent variables used in the regression and variance analyses respectively. Therefore, the first part of the questionnaire was concerned with measuring the demand placed on change-of-mode facilities (Fig. 1). The measurement of change-of-mode demand included the determination of the number of park-and-ride vehicles, kiss-and-ride vehicles, and change-of-mode passengers that used the parking facility each day. An average weekday demand was sought. Yearly, daily, and hourly, both peak and nonpeak, variations occur in the demand. Overflow of parking lots takes place, and a knowledge of the extent of the overflow is needed to determine the actual demand for change of mode.

The demand for change-of-mode parking depends on the characteristics of the transit serving the facility. The second part of the questionnaire (Fig. 2) obtained information on the type of transit, headways, fares, travel times, and adequacy of the distribution network at the downtown end of the trip.

The third part of the questionnaire concerned measurements of the physical characteristics of the parking lot (Fig. 3). The adequacy of lighting, egress and ingress, delineation, and pavement condition are considered to be measures of the physical characteristics. The quality of the transit terminal and the walking distance from parked car to transit platform are also necessary measures.

The fourth part of the questionnaire (Fig. 4) measured the operational characteristics of the facility, and the fifth part (Fig. 5) measured the location of the change-of-mode facilities within the metropolitan area. General questions were asked in the sixth part (Fig. 6).

A total of 357 questionnaires were mailed to 60 agencies in 12 metropolitan areas. Information was requested for 134 facilities at which the transfer is to rail and for 36 facilities at which the transfer is to bus transit. Twenty-six agencies replied and gave information concerning 73 rail and 20 bus change-of-mode facilities. As a result of the survey, 190 usable observations are made.

Table 1 gives the number of observations desired and obtained by metropolitan area and type of transit. The percentage of questionnaires that were usable, unusable, and unreturned is as follows:

Condition	Bus	Rail
Usable	50.8	53.9
Unusable	32.8	16.2
Unreturned	16.4	29.9
Total	100.0	100.0

The number of mailed and usable questionnaires per change-of-mode facility is as follows:

Mode	Mailed	Usable
Bus	2.03	1.81
Rail	2.12	2.09
Avg	2.10	2.03

The data were used to analyze change-of-mode demand. That required a minimum of variables so that the significance and reliability of the statistical analysis could be maximized. Therefore, the need for combining the many data items into more representative and comprehensive variables was evident.

Basic Concepts

Two classes of aggregate variables were developed. The first type comprised all data items that were independent of the characteristics of parking lots. The variables thus constituted were considered to behave as parameters when parking lot demand is

Figure 1. Questions relating to demand.

1. What is the average number of park&ride vehicles that use the facility, by year, since the beginning of parking service? (veh/day) SELECT ONE YEAR (DATE ______________) FOR WHICH YOU ARE SUPPLYING ANSWERS TO THE QUESTIONS THAT FOLLOW.	______ 1st year ______ Date ______ 2nd year ______ 3rd year ______ 4th year ______ 5th year ______ 6th year ______ 7th year ______ 8th year ______ 9th year ______ 10th year ______ present
2. What is the average number of park&ride vehicles that use the facility?	______________ (veh/day)
3. What is the average number of kiss&ride vehicles that use the facility?	______________ (veh/day)
4. What is the average number of transit passengers that transfer from atuo?	______________ (persons/day)
5. What is the average number of transit passengers that board at facility?	______________ (persons/day)
6. What is the average number of transit passengers that board at facility, by day of the week? (persons/day)	______ Monday ______ Tuesday ______ Wednesday ______ Thursday ______ Friday ______ Saturday ______ Sunday
7. What is the proportion of morning peak park&ride vehicle arrivals to total vehicle arrivals within an average day?	______________ %
8. Is there any indication that a substantial number of transit passengers park outside the parking facility? If answer is yes, please give proportion of outside to inside parked vehicles.	O ..... Yes O ..... No ______________ %

Figure 2. Questions relating to transit service.

1. What is the type of the transit system being served by parking facility?	O ..... bus O ..... rail
2. What is the average headway between transit vehicles serving facility during peak periods?	______________ min.
3. What is the transit fare from facility to downtown of metropolitan area?	______________ cents
4. What is the overall travel time by transit, from facility to downtown of metropolitan area?	______________ min.
5. What is the proportion of jobs in the downtown area (as compared to other cities) that is reached, within acceptable walking distance, by the transit system being transferred to?	O ....high O ..... average O ....low

Figure 3. Questions relating to physical characteristics.

1. What is the lighting condition at the parking facility?	○..... good ○..... adequate ○..... poor ○.......... none
2. Is the facility well enclosed with adequate entrances and exits?	○..... yes ○..... fair ○..... no ________ exits ________ entrances
3. Under what category does the transit terminal fall?	○...... Luxurious building ○....... adequate building ○...... sheltered platform ○........... platform only
4. Under what category does the facility pavement fall?	○ ..... well paved with markings ○ .... treated surface ○ .... gravel
5. What is the average walking distance from facility parked cars to transit platform?	____________________ feet

Figure 4. Questions relating to operational characteristics.

1. Does the facility include any kiss & ride stalls? If answer is yes, please give number.	○..... yes ○...... no ____________________ stalls
2. Does the facility have any bus berths? If answer is yes, please give number of regular buses that stop at these berths.	○..... yes ○...... no ____ buses/peak hour ____ berths
3. How many hours within the day is the facility operational?	____________________ hours
4. How many days within the week is the facility operational?	____________________ days
5. How would you classify the maintenance level provided at the facility?	○..... Good ○..... Adequate ○..... Poor ○.......... None
6. What is the parking charge at facility?	____ cents/hour ____ dollars/day
7. How many park&ride stalls are there at the facility?	____________________ stalls
8. Does the facility have any attendants? If answer is yes, please give number of attendants.	○ ..... yes ○ ..... no ____________________ attendants
9. Is the parking facility operated for the sole use of the transfer passengers? If answer is no, please indicate the nature of the other usages.	○..... yes ○..... no ____________________ ____________________

Figure 5. Questions relating to location of facility.

1. What is the major land use type in which the parking facility is located?	○ ..... Resd'l ○ ..... Res+Ind ○ ..... Comm'l ○ .... Ind'l ○ .... Rs+Com ○ ..... Rs+Ind+Com
2. What is the aerial distance from facility to downtown center of metropolitan area?	________ miles
3. What is the aerial distance from facility to nearest competitive facility?	________ miles
4. What is the aerial distance from facility to next lower transit fare zone?	________ miles
5. What is the distance from main facility entrance to major highway arterial access?	________ blocks
6. What is the name of this major highway arterial access?	________
7. What is the ADT of this major highway arterial access?	________ Vpd
8. How many lanes does this major highway arterial access have?	________ lanes
9. How visible is the facility from its major highway arterial access?	○ .... quite visible ○ .... slightly visible ○ ....Info. signs are posted ○ .... not visible

Figure 6. General questions.

1. Who owns the parking facility?	________
2. Who operates the facility?	________
3. Are transfers between transit systems and/or lines allowed in metropolitan area served? If answer is yes, please give the charge for such transfers.	○ ..... yes ○ ..... no ________ cents
4. Does the transit system being transferred to at the facility have more than one fare zone? If answer is yes, please give number.	○ .....yes ○ ..... no ________ Fare zones
5. What is the average overall travel speed within metropolitan area, by type of transit?	____ Mph ____ Transit type ____ Mph ____ Transit type ____ Mph ____ Transit type
6. How would you classify the parking condition in the downtown of metropolitan area served by facility?	○ .... Intolerable ○ .... Problematic ○ .... Worrisome ○ .... little to worry
7. At what distance from downtown, along arterial corridors, would you estimate the traffic to become heavily congested during the morning peak period?	________ miles

predicted. Three aggregate variables were in this category: transit service rating, metropolitan area rating, and parking facility location rating.

The variables that measure the parking lot characteristics made up the second class. Successful change-of-mode design criteria were developed by finding those values of this class that optimized the savings that accrue to the community. The 5 variables that were developed are facility safety rating, rating for physical quality of facility, facility reliability rating, facility flexibility rating, and facility parking fee rating.

Each aggregate variable was made up of a combination of data items (factors). Once an item was included in the formulation of a variable, it did not enter in the formulation of any other. Data items were combined in an additive manner or a multiplicative manner or a combination of both. The decision to add or to multiply the effect of different factors was intuitively based on the manner in which a commuter would combine the factors in the process of choosing change of mode over passenger car.

To each of the factors that made up a given aggregate variable was attached an average rate that measured its relative influence in the decision-making process of a commuter trying to choose between change of mode and passenger car. It is worth noting that, at this stage, there was no need to worry about the relative importance of variables because an additive regression model was to be developed eventually.

A set of discrete levels was formulated in order to measure the variation within factors. For each factor, a different rate was attached to each of its levels. For any given factor, the rates of its levels varied around its previously assigned average relative rate.

In this manner many qualitative (discrete) and quantitative (continuous) factors were combined to create a smaller number of mainly integer-valued variables. It should be noted that the whole process of rating the different factors and their levels and of combining factors was based on subjective engineering judgment. That judgment is based on an exhaustive evaluation of the previous literature in the field of modal split and on a study of commuter decision-making considerations.

A variable that measures some of the characteristics of a parking facility requires that a unique solution be obtained for those parking lot characteristics once a value is assigned to that aggregate variable. If an economically optimal set of values for all such variables were found, then it would be possible to determine all the associated parking lot characteristics. The lot characteristics thus determined were the design criteria we sought.

Sample Development—Transit Service

The reason for this choice is that the transit service rating was found to be significant in both the analysis of variance and the regression analysis. Also, this aggregate variable involved the combination of factors by both addition and multiplication and comprised discrete and continuous factors.

The transit service rating is made up of the following factors: (a) quality of station terminal building, (b) transit fare to the downtown, (c) overall corridor travel speed of transit, (d) proportion of downtown jobs easily reached by the transit being transferred to, (e) availability and cost of transfer within transit system, (f) number of transit fare zones, and (g) ticket marketing and collection methods.

Factors e through g are measures of the flexibility of the transit system available at the change-of-mode parking facility. A commuter will define flexibility as the addition of these 3 factors.

The transit service rating is given by Eq. 1.

$$\text{Transit service rating} = (\text{station terminal building} + \text{transit fare}) + (\text{transit speed} \times \text{transit flexibility}) \quad (1)$$

Equation 1 implies that

1. The effects of transit speed and flexibility are multiplicative as far as the commuter is concerned; and

2. The commuter's sense of aesthetics (quality of terminal), his cost considerations (out-of-pocket transit fare), and his comfort and convenience (transit speed and flexibility) are additive.

The 7 factors that combine to describe the transit service were each subdivided into discrete levels. A rate was assigned to portray the influence of every level in the commuter's decision-making process. The levels and their associated rates, which are given in Table 2, require some explanatory remarks.

First, the average rates for quality of terminal, for transit fare, and for transit flexibility (sum of the last 3 factors) are all equal to four. This fact implied that the 3 factors have an equal influence on choice of mode.

Second, the average rate for transit speed is equal to 12 and to the sum of the average rates of all other factors. Modal-split models have all recognized the importance of speed, and the rate assignment stated above takes that importance into account. The implication of such rate assignments is that transit speed is as important to the commuter as the sum of all other factors. In other words, a decrease in the transit speed level if accompanied by a comparable increase in the level of all other factors will not change the decision of a commuter choosing between change of mode and passenger car because the transit service rating will be unchanged.

Third, the transit service improves with an increase in the quality of the station terminal, a decrease in the transit fare, an increase in overall transit travel speed, an increase in the proportion of CBD jobs easily reached by transit, the availability of low-cost transfers, the existence of more than one fare zone, and an increase in the quality of ticket marketing and collection methods.

As an example, a transit service rating is computed for a change-of-mode parking facility that has the following factors:

1. Adequate station terminal at the change-of-mode lot;
2. Transit fare of 40 cents or 6.67 cents/mile (the station is 6 miles from the central business district);
3. Transit travel time from station to downtown of 16 min, a peak headway of 5 min, and an overall travel speed of 19.5 mph;
4. Transit distribution network in the downtown area easily in reach of a low proportion of jobs;
5. No transfers within the transit system;
6. Two fare zones in the transit system; and
7. Good ticket marketing and collection methods.

Rates for these factors (Table 2) are 4, 3, 9, 1, 0, 1, and 1. Combining these rates according to Eq. 1 gives

$$\text{Transit service rating} = (4 + 3) + (9 \times 1 + 0 + 1 + 1) = 34$$

Seven factors were combined to obtain an integer-valued variable that will be used to predict change-of-mode parking demand. Methods used in developing the remaining aggregate variables (i.e., the factors involved in each variable and the levels and associated rates for each factor) are also given in Table 2 and shown in Figure 7. The equations used to combine the factors into aggregate variables are given below. Table 3 gives the results of the modeling technique.

$$\text{Transit service rating} = (\text{station terminal building} + \text{transit fare}) + (\text{transit speed} \times \text{transit flexibility}) \quad (1)$$

$$\text{Metropolitan area rating} = \text{transit speed} + \text{CBD parking congestion} + \text{radial highway congestion} + \text{metropolitan area population} \quad (2)$$

Table 1. Questionnaires mailed, returned, and usable.

Metropolitan Area	Mailed		Unreturned		Returned		Unusable		Usable	
	Bus	Rail	Bus	Rail	Bus	Rail	Bus	Rail	Bus	Rail
Milwaukee	13	—	—	—	13	—	—	—	13	—
Baltimore	3	—	—	—	3	—	—	—	3	—
Washington	35	—	—	—	35	—	21	—	14	—
New York	2	59	—	23	2	36	—	32	2	4
Chicago	2	99	2	54	—	45	—	12	—	33
Pittsburgh	—	5	—	—	—	5	—	—	—	5
Cleveland	4	44	2	—	2	44	2	—	—	44
Miami	6	—	6	—	—	—	—	—	—	—
Boston	6	57	—	—	6	57	1	2	5	55
Philadelphia	—	14	—	8	—	6	—	—	—	6
Toronto	—	6	—	—	—	6	—	—	—	6
Newark	2	—	2	—	—	—	—	—	—	—
Total	73	284	12	85	61	199	24	46	37	153

Table 2. Factor ratings.

Variable	Factor	Level	Rate
Transit service	Quality of transit station terminal	Transportation center with extra services	10
		Luxurious	7
		Adequate	4
		Shelter	2
		None	1
	Transit fare to CBD, cent/mile	< 4	5
		< 4 ≤ 6	4
		< 6 ≤ 10	3
		< 10 ≤ 20	2
		> 20	1
	Transit overall speed, mph	≥ 30	24
		≤ 20 < 30	15
		≤ 15 < 20	9
		≤ 10 < 15	6
		< 10	3
	Proportion of CBD jobs reached by transit	High	4
		Average	2
		Low	1
	Transfer availability, cost within transit	Available, 10 cents and less	1
		Not available, or available and more than 10 cents	0
	Transit fare zones, more than one	Yes	1
		No	0
	Ticket marketing and collection methods	Innovative	2
		Good	1
		Adequate	0
Metropolitan area	Representative transit speed in metropolitan area, mph	< 20	10
		< 15 ≤ 20	6
		< 10 ≤ 15	4
		≤ 10	2
	Condition of parking in CBD	Intolerable	5
		Problematic	3
		Worrisome	2
		No worry	1
	Distance from CBD where heavy congestion starts, miles	< 8	8
		< 5 ≤ 8	6
		< 3 ≤ 5	4
		≤ 3	2
	Metropolitan area population, × 10^6	< 2.5	9
		< 1.0 ≤ 2.5	6
		< 0.5 ≤ 1.0	3
		≤ 0.5	1
Facility location	Distance to lower fare zone, miles	< 5	5
		< 2 ≤ 5	3
		< 1 ≤ 2	1
		≤ 1	0
	Distance to nearest competitive facility, miles	< 5	3
		< 2 ≤ 5	2
		< 1 ≤ 2	1
		≤ 1	0
	Distance to highway access, blocks	< 2	3
		≤ 2 < 5	2
		≤ 5	1
	Width of highway access, lanes	> 4	6
		4	3
		< 4	1

Table 2. (continued).

Variable	Factor	Level	Rate
Facility location (continued)	Visibility of facility from access	Quite visible	3
		Slightly visible	2
		Information signs are posted	1
		Not visible	0
	Distance from facility to CBD, miles	< 16	10
		< 12 ≤ 16	8
		< 8 ≤ 12	6
		< 4 ≤ 8	4
		< 2 ≤ 4	2
		≤ 2	0
	Surrounding land use type	Res.	6
		Res.-Comm.	4
		Comm.	3
		Res.-Ind.	2
		Res.-Ind.-Comm.	1
		Ind.	0
	Surrounding residential density, 10^3/sq mi	< 22	7
		< 16 ≤ 22	5
		< 10 ≤ 16	3
		< 4 ≤ 10	1
		≤ 4	0
Facility safety	Condition of lighting in facility	Good	3
		Poor	2
		Fair	1
		None	0
	Availability of enclosures, number of gates/200 stalls	Yes, > 1	3
		Yes, ≤ 1	2
		Fairly enclosed	1
		None	0
Physical quality	Type of pavement at facility	Paved, marking, and landscaping	8
		Paved and marking	6
		Treated surface	4
		Gravel	2
	Avg walking distance from facility to station, ft	< 300	4
		≤ 300 < 500	3
		≤ 500 < 700	2
		≤ 700	1
Facility flexibility	Agency type of facility owner	Transportation or planning or both, public or private	2
		Other	1
	Agency type of facility operator	Same as transit operator	2
		Different from transit operator	0
	Proportion of kiss-and-ride stalls to total stalls, percent	< 6	8
		< 3 ≤ 6	4.5
		< 1 ≤ 3	2.0
		< 0 ≤ 1	0.5
		0	0.0
	Availability of connecting bus lines	Yes	10
		No	0
Facility reliability	Days/week operated	7	2.0
		6	1.0
		≤ 5	0.4
	Hours/day operated	< 20	2.0
		≤ 12 ≤ 20	1.0
		< 12	0.4
	Attendant availability, number/200 stalls	Yes, < 1.5	10
		Yes, < 0.5 ≤ 1.5	5
		Yes, ≤ 0.5	2
		No	0
	Maintenance quality	Good	5.0
		Adequate	2.5
		Poor	1.0
		None	0
Facility parking fee	Dollar/day	0.00	6
		< 0.00 ≤ 0.20	4
		< 0.20 ≤ 0.50	3
		< 0.50 ≤ 1.00	2
		< 1.00	1
Years from start	Years from polling to start of operation	≤ 1	0
		≤ 2 ≤ 6	1
		≤ 7	2

Facility location rating = (distance to fare zone x distance to competition)
+ (distance to access x width of access)
+ visibility from access + distance to CBD
+ (surrounding land use type + residential density) (3)

Facility safety rating = facility lighting + availability of enclosures (4)

Physical quality rating = pavement type + walking distance (5)

Facility flexibility rating = (agency type of owner x agency type of operator)
+ availability of bus berths
+ proportion of kiss-and-ride stalls (6)

Facility reliability rating = days of operation + hours of operation
+ availability of attendants + maintenance quality (7)

PARKING LOT USAGE

This section reports on the procedure employed and the findings of the analysis of variance for the effect of the aggregate variables on change-of-mode parking lot usage. The analysis of variance is based on 190 observations made for more than 93 facilities in 10 metropolitan areas.

ANALYSIS OF VARIANCE

The object of the statistical analysis was to study the trends and significance of the effects of the parametric and design variables on the use of change-of-mode parking lots. It should be understood that the use of a lot measures its success in attracting change-of-mode parkers.

The 28 two-way classifications analysis of variance was performed at the Purdue University Computer Science Center. UNEQUAL is the name of the statistical computerized library program that was used to build the analysis of variance tables.

Tables 4 and 5 give the results of all 28 ANOVA tables. Table 4 gives the main effects of the ratings; the variables are the same as those given in Table 3. The values given in both tables are the ratios of the computed F's and their associated 0.1 critical F's. Values of 1.00 and more, for this ratio between F's, imply that the computed F is equal to or larger than the critical F. Under such circumstances the hypothesis of nonsignificance is rejected. When the ratio between F's is smaller than one, then the hypothesis of nonsignificance cannot be rejected.

The result of the analysis of variance led to the following conclusions. (Tables 4 and 5 should be referred to as the conclusions are read.)

1. The main effects of the metropolitan area rating are significant in all of the 7 cases in which they appear. The same applies in the case of the facility safety and the facility reliability ratings. These 3 factors do affect the usage of change-of-mode parking lots.

2. The main effects of the facility location rating are always found to be not significant. Four possible reasons could explain this finding. First, the modeling of the location rating could be inadequate; second, the location rating interacts to a high degree with other factors; third, the location rating truly does not affect the usage of parking facilities; or, fourth, and most likely, a high percentage of the transit facilities reporting had very good locational characteristics, which provide low variation in the location rating. Variables with low variation are generally found to be not significant.

3. The main effects of the remaining ratings (transit service, physical quality, flexibility, and parking fee) are found to be significant in more than half of the cases in which they are involved. The data seem to suggest that these factors significantly affect the use of change-of-mode parking facilities.

Figure 7. Residential density as function of location within city and metropolitan size.

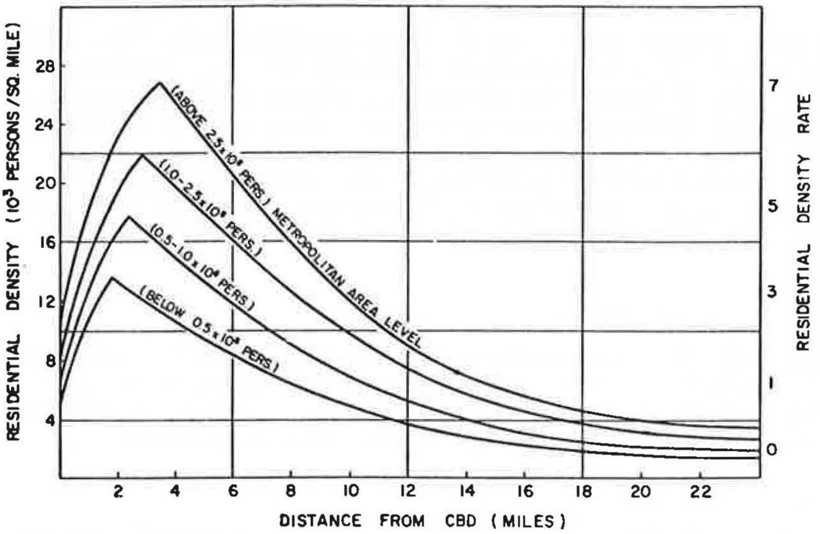

Table 3. Summary of aggregate variables.

	Theoretical Range		Sample Range		Sample Average	
Variable	Min	Max	Min	Max	ANOVA	Regression
Transit service	5	212	14	99	48.30	48.32
Metropolitan area	6	32	14	30	22.78	21.61
Facility location	0	88	6	64	33.83	34.21
Facility safety	0	6	1	6	4.03	3.74
Physical quality of facility	3	12	6	10	8.92	9.22
Facility flexibility	0.0	22.0	0.0	18.0	5.23	6.48
Facility reliability	0.8	19.0	3.0	17.0	6.61	5.85
Facility parking fee	1	6	2	6	4.28	4.40

Table 4. Ratio of computed and critical F for main effects of ratings.

Associated Variable	Variable T	M	L	S	Q	F	R	P
T		4.78	0.90	1.58	1.11	5.30	2.06	1.69
M	0.33		0.56	3.26	0.74	2.13	3.78	0.22
L	1.73	8.21		2.78	1.47	1.32	5.15	2.38
S	0.35	2.69	0.30		2.32	2.43	4.49	1.39
Q	0.69	3.50	0.33	5.09		2.63	6.43	1.12
F	1.38	7.95	0.60	3.48	1.26		7.35	2.41
R	1.06	3.99	0.18	1.12	0.63	0.78		0.14
P	1.43	2.28	0.41	3.16	0.79	2.32	4.27	

Table 5. Ratio of computed and critical F for interactions among ratings.

Second Variable	First Variable T	M	L	S	Q	F	R	P
T		1.47	1.58	0.87	1.85	0.66	1.46	1.95
M	1.47		0.79	1.41	0.65	0.01	0.93	1.80
L	1.58	0.79		1.07	1.10	1.35	0.98	0.11
S	0.87	1.41	1.07		2.79	0.49	0.99	2.36
Q	1.85	0.65	1.10	2.79		0.03	0.71	0.59
F	0.66	0.01	1.35	0.49	0.03		1.68	1.88
R	1.46	0.93	0.98	0.99	0.71	1.68		0.99
P	1.95	1.80	0.11	2.36	0.59	1.88	0.99	

4. Most of the interaction terms that contain the transit service rating, the location rating, or the parking fee rating are found to significantly affect the use of parking facilities. These findings seem to indicate that the extent to which a facility is used is based on combining these 3 factors with the design factors (safety, quality, flexibility, and reliability).

5. The large number of effects that were found to be significant indicates that the change-of-mode phenomenon is quite complicated. The fact that most main effects are significant tends to give credence to the modeling technique that was used to develop ratings.

PARK-AND-RIDE DEMAND

This section reports on the development of a multiple linear regression equation to predict the change-of-mode demand. This equation would apply in all metropolitan areas of the continental United States and for the forseeable future as long as no major changes occur in present travel and traffic trends, based on the sample taken.

Procedure of Analysis

In the absence of an established theory regarding change-of-mode demand, one can only assume a model form. One of the possibilities is an additive model. Therefore, one should view the linear equation as only an estimate or an approximation until further evidence is available.

A regression equation was developed to predict the number of park-and-ride vehicles. The equation was later tested to see whether it satisfied the statistical constraints placed on the error term in the regression model. The Bartlett test for homogeneity of variance was used to test for both normality and independence. The Bartlett test produced a high chi-square, indicative of the fact that the equation violated its inherent constraints. For this reason, the dependent variable was mathematically transformed into its square root, and the whole process was repeated.

Prediction Equation

The discussion that follows reports on the chosen park-and-ride demand prediction equation. The statistical qualities of the equation are given, and comments are made on the makeup of the equation. Also, both sensitivity and applicability analyses were performed, although only the application is reported.

Results

Equation 8 is the chosen prediction equation.

$$\sqrt{D} = -0.70479 + 0.00940\ Z + 1.96438\ B + 1.21122\ R + 0.00088\ T^2 + 0.00867\ M^2 + 0.04868\ F \cdot P - 0.01929\ T \cdot R \quad (8)$$

where

- D = number of park-and-ride vehicles that use a facility during a 24-hour period;
- Z = number of stalls within a change-of-mode parking facility;
- B = type of transit being transferred to at the facility (bus on highway right-of-way = 0, and rail and bus on exclusive right-of-way = 1);
- R = reliability rating of the change-of-mode parking facility;
- T = transit service rating at the change-of-mode parking facility;
- M = metropolitan area rating for the change-of-mode parking facility;
- F = flexibility rating of the change-of-mode facility; and
- P = parking fee rating of the change-of-mode facility.

Table 6 gives the statistical qualities of the chosen prediction equation. Equation 8 explains 78 percent of the variation in the park-and-ride demand and has a multiple correlation coefficient of 0.88. All the independent variables are significant at the 95 percent level, and all but one are significant at the 99 percent level. The equation on the whole, with an F-ratio of 44.2, is significant at a much higher rate than 9,995 in 10,000. The standard error of the estimate is equal to 2.93, which implies that the 95 percent confidence interval of an estimate is from 56 to 369 parked vehicles/day.

The chosen equation was tested for homogeneity of variance by using the Bartlett test. A chi-square equal to 5.81 was obtained with 4 degrees of freedom. Because the critical chi-square at the 10 percent level (7.78) is larger than the computed one, the hypothesis of homogeneity of variance and normality of the error term is accepted.

Two of the design ratings did not enter into the prediction equation. The safety rating had a high correlation with the reliability rating, and the physical quality rating was substantially correlated to the parking fee rating. Both the reliability and the parking fee ratings affected the park-and-ride demand more significantly, and once in the equation they barred the entry of the latter two.

Application Test

At this point, a check on the ability of the regression equation to predict the park-and-ride demand seemed appropriate. For this purpose, the data from the Institute of Traffic Engineers survey were used to test how well the equation predicted the number of parked vehicles at a change-of-mode lot. Of the 179 facilities that the ITE surveyed, only 9 were used. The remaining 170 facilities either coincided with data collected and previously used in developing the equation, did not contain the necessary information to compute the independent variables, or had a demand that exceeded the supply.

The applicability of the prediction equation was tested by 2 different methods. The first test was on the hypothesis that the mean difference between estimated and measured park-and-ride demand is equal to zero. The student-t test was used to either accept or reject the hypothesis. Table 7 gives the observed and estimated park-and-ride demand and the difference between them for the 9 checked facilities. A student-t of 0.91 was computed by using the paired-comparison difference between observed and estimated demand. The hypothesis that there is no difference between observed and estimated demand is accepted well beyond the 20 percent level. The critical student-t for an α of 0.2 and 8 degrees of freedom is equal to 1.40, which is much larger than the computed one. Because the hypothesis is accepted even at an α of 0.2, this indicates that the probability of accepting when one should reject is very low.

Next, the individual estimates were tested. For this purpose, a least square regression equation was developed for the observed demand; the estimated demand was the sole independent variable. If the individual estimates are equal to the corresponding observed demand, then the equation would have a 0 intercept ($b_0 = 0$) and a slope of 45 deg ($b_1 = 1$). An F-ratio was used to test the hypothesis that the regression equation for the estimated versus observed demand possesses b_0 and b_1 coefficients that are equal to 0 and 1 respectively. Simultaneously, an F-ratio of 1.22 was computed, and the hypothesis is accepted up to the 34 percent level.

In conclusion, an equation that satisfied the statistical constraints that are inherent in a linear regression model has been developed. This equation is also able to reliably predict the park-and-ride demand at different facilities and in different metropolitan areas.

CONCLUSIONS

Statistical evidence indicates that most ratings of the developed characteristics are significant in affecting change-of-mode parking facility usage. An increase in the metropolitan area, facility reliability, and facility safety ratings causes a significant increase in the occupancy of change-of-mode parking facilities.

Because no control over the collected data could be exercised, no clear-cut decision on the effect of the facility safety, facility flexibility, and transit service ratings could be taken. The facility location rating was found to be insignificant in affecting the use of parking facilities.

A study of the park-and-ride demand prediction equation would indicate that all of its independent terms contribute almost equally in estimating the demand. All of the independent terms are positively proportional to the park-and-ride demand. In other words, an increase in the value of any independent variable would result in an increase in the estimate of the demand.

The independent variables that predict the park-and-ride demand are the size of the facility, its flexibility, reliability, and parking fee ratings, and the metropolitan area and transit service ratings associated with the change-of-mode parking facility. Four of the 6 ratings that measure the design characteristics of the parking facility are included in the prediction equation. This fact substantiates the method used in developing the ratings from the survey data. The facility safety and physical quality ratings did not enter the prediction equation because of their correlation with other ratings already included. The fact that two-thirds of the demand estimate is due to parking facility design characteristics points up the importance of these characteristics. Many of the existing methods fail to include these characteristics.

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DISCUSSION

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Regional Transit Service has been engaged in the development of a park-and-ride network for about 1½ years. When one attempts to estimate demand for such new service from a new suburban terminal, the lack of an applicable methodology that is comprehensible and useful to an operator in a medium-sized metropolitan area becomes evident. For this reason, the research effort by the authors is needed and appreciated.

Several elements of the paper are clearly commendable from this viewpoint: (a) the attempt to enumerate determining variables for park-and-ride usage; (b) the attempt to develop a methodology for estimating parking usage; and (c) the emphasis of the importance of developing procedures for estimating intermodal transfer. These elements would appear to justify the paper.

However, certain questions must be addressed with regard to the use of the research by an implementing agency. A discussion of the data and data gathering procedure is primary. The basic concepts and the authors' discussion of the variables and factors must be evaluated. Finally, the conceptual development of their hypothesis and their resultant conclusions should be examined in terms of validity.

I am neither a mathematician nor a statistician and am thus not qualified to evaluate the mathematical procedures used. (It should be noted that few implementing agencies, particularly transit operators, have the trained personnel available who could comprehend, or apply, the equations used.) Regional Transit Service, however, now uses 22 shared-use parking lots for 5 park-and-ride routes that have a total of 11 branches and 5 people-generator destinations (2 of which are located in the CBD) and carries approximately 2,500 passengers/day. My comment is, therefore, based on fairly extensive operational experience, though limited to only 1 metropolitan area.

Of primary concern to an operator (beyond the basic comprehensibility) is the reliability of the data collection methodology and the subsequent validity of the data of the work. The questionnaire used to develop data seems to ask highly subjective questions. The questions themselves appear to be based on prior determination by the authors of the important variables. In certain semantic differential questions, a highly subjective evaluation was required of change-of-mode operators. Based on my experience, biased answers that are likely to be barely relevant and reliable may result, but not "hard" data.

Further, response was requested from a very small number of cities of limited geographic and size distribution. Barely more than 50 percent of the responses (particularly for bus transit) were usable. The distribution of the responses, again particularly for bus transit, is even more limited than the original distribution of questionnaires. The extremely heavy emphasis on modal transfer to rail is curious, when one considers that comparatively few metropolitan areas have rail transit. Such emphasis is even more curious when conventional commuter railroad, light-volume rail transit, and heavy-volume subway appear to be considered as the same mode in the questionnaire and subsequent data. These 3 rail modes have greatly different rider characteristics; it is suggested that they cannot be so easily compared and combined in data analysis as the authors imply.

The authors' basic concepts and the subsequent factors and variables, as stated in the paper, must be challenged. Fundamentally, the concept of predicting park-and-ride parking demand as independent of park-and-ride ridership is a questionnable exercise. Although the authors mention access to the parking facility by those who do not travel by automobile, the appropriate emphasis is not given to kiss-and-ride, pedestrian access, car pools, feeder bus service, and even bicycle. Such an omission can greatly reduce the validity of an estimation model and related procedures, for line-haul riders arriving by means other than 1 person-1 car can account for significantly more riders than facility users. In an on-board ridership survey conduced by Regional Transit Service, the question, How do you usually get to the park-and-ride bus stop in the morning? was asked. Figure 8 shows the responses.

The stress on metropolitan and city characteristics (as compared to corridor characteristics) should be disputed. Various corridors of a metropolitan area are likely to possess highly dissimilar characteristics that will lead to erroneous conclusions. For example, the population of a sample metropolitan area, the distance from the CBD where heavy congestion commences, the condition of parking in the CBD, and a representative transit speed—factors used by the authors—can, in certain instances, lead to a very low rating. Yet, microanalysis of a particular corridor within the same metropolitan area can result in a very high rating for that particular corridor. In Rochester, certain radial corridors are highly congested several miles out, yet a parallel route a mile or two away is basically uncongested until a traveler reaches the core of the CBD.

The characteristics of the transit service factors are incomplete and contain several irrelevancies. Basic to the commuter's decision to transfer between modes is the comparability of transit service—bus or rail—to alternative travel modes. The transit service is of primary importance, but only as related to the perceived cost of alternative travel modes. The authors fail to evaluate the importance of the perceived cost of alternative modes, especially such an important out-of-pocket cost as parking fees. The number of fare zones (as differentiated from the authors' transit fare) is relevant only if there is a "nuisance payment"; if the zones are purely administrative boundaries for the development of the appropriate fare levels by the operator, then fare zones lack meaning for the rider and the operator.

Other characteristics that should have been discussed in the paper include the relative comfort of the transit mode; when transit vehicles operate in mixed traffic, that can be crucial, but "merely" important when they operate on exclusive rights-of-way. The headway of the transit service may be important, but it must be related to the desired travel times of the commuters. That is frequently defined as the perceived convenience factor in the commuter's decision to change modes. A person who has to arrive at the CBD terminal (or station) at 8:20 a.m. to be able to get to work at 8:30 a.m. does not want to arrive at 8:25 or 8:30; nor may the rider be willing to arrive excessively early, as he (and only he) perceives that to be. A transit schedule oriented to specific travel needs is not likely to have a commonly defined headway within such a connotation. Most important to the rider is the day-to-day reliability of the system somewhat related to the headway. If the operating timetable is almost always dependable (again, as perceived by the user), he is more likely to ride.

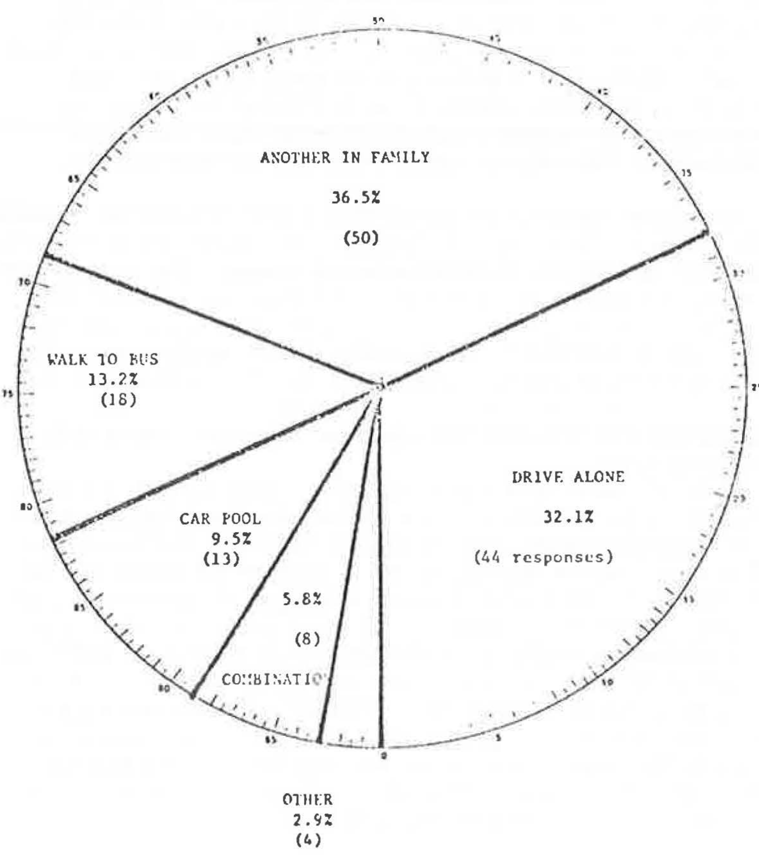
Table 6. Statistical qualities of prediction equation.

Step	Variable	Regression Coefficient	Standard Error	F-Ratio	R^2	Increase in R^2
		-0.70479				
1	Z	0.00940	0.00095	98.4812	0.6244	0.6244
2	B	1.96438	0.90511	4.7103	0.6957	0.0713
3	F·P	0.04868	0.01255	15.0351	0.7105	0.0149
4	R	1.21122	0.26075	21.5779	0.7289	0.0183
5	M^2	0.00867	0.00291	8.8602	0.7413	0.0124
6	T·R	-0.01929	0.00509	14.3574	0.7564	0.0151
7	T^2	0.00088	0.00030	8.8465	0.7786	0.0222

Table 7. Observed and estimated park-and-ride demand.

Observed		Estimated		
$\text{Cars/Day}^{1/2}$	Cars/Day	$\text{Cars/Day}^{1/2}$	Cars/Day	Difference
5.00	25	6.64	44	-1.64
22.36	500	17.62	311	4.74
20.00	400	15.37	235	4.63
10.72	115	11.88	141	-1.15
8.06	65	5.70	33	2.37
11.00	121	8.42	71	2.58
27.39	745	18.33	336	9.06
7.42	55	13.51	183	-6.09
10.30	106	12.38	153	-2.08

Figure 8. Mode used to arrive at park-and-ride bus stop.



A final consideration is the conceptual development of the paper. Decisions in intermodal transfer by commuters cannot be done "intuitively." Such decisions must be based on reliable measures, factors, and data, developed through research based on determining and evaluating the perceptions of alternative travel modes by corridor residents: riders, potential riders, former riders, and nonriders. Subjective engineering judgment must be based on an analysis of the characteristics of comparable corridors, not merely on literature searches. Subjective rating of factors and variables not based on aggregated perceived rider values, correlated to observed ridership behavior patterns, is of little use to an operator, particularly one attempting to maximize ridership and revenue.

To conclude, it is felt that the exercise by the authors fulfilled the objective of leading to the increase of knowledge concerning park-and-ride, an increasingly important transportation tool. However, the hypothesis and conclusions are highly suspect because of the concepts, methodology, and evaluations of the authors. Operational efforts in the development of new and improved service need far greater precision and analysis in the model than those presented in this paper.

AUTHORS' CLOSURE

As always, authors sit in hope that someone will take the time to critically discuss their paper. It opens the door to overriding the page limit to get a few more items clear. The first draft of this research said it all, but it was 250 pages long; the final manuscript was reduced to about 150 pages. The quantum jump to an 18-page paper can be critical.

The points raised by Alter will be acknowledged one by one. From an extensive review of the literature one would find very little data to suggest what specific variables might contribute to estimating parking demand at park-and-ride facilities. An unpublished ITE report and Highway Research Board Circular 26 by the Committee on Parking are the only 2 pertinent references. We do not agree that the data were highly subjective.

Two factors influenced the selection of the data collection method. First, we were financially constrained by a limited budget. Second, the extensive geographic distribution would have placed a strain on all but a most lucrative budget. Therefore, it was necessary to rely on data already collected or easily provided by change-of-mode operators. On that basis, it was decided that a questionnaire should be sent to change-of-mode operators. The literature was used as a starting point to solve the problem of where to send the questionnaires. A preliminary study was performed to find additional names and addresses of change-of-mode operating agencies and of the responsible personnel. Correspondence was started with the change-of-mode operators to elicit as much of the pertinent information as feasible. Through the fine cooperation of the operators, it was possible to devise an extensive and feasible questionnaire.

The third and last part of the experimental design was to select the facilities to be investigated from among those that fall within the scope of the project. Successful and unsuccessful facilities were polled so that the statistical analyses would not be biased. To ensure that there was an adequate variation within all proposed independent variables, we decided to include all facilities known (to us and operators contacted). Many of the change-of-mode parking facilities have been in use for a long period of time. During this time, many of the characteristics and the demands have radically changed. For this reason, it was decided, wherever feasible and warranted, to make observations at different points in time.

In those few instances where the questionnaire asked for a qualitative response of high, average, or low, it would have been a difficult data collection process to be more specific. Most data items were quantified to the degree feasible. For example, lighting conditions at the facility were noted as good, adequate, or poor. The level of analysis did not require measurements of footcandles; had it done so, where would one make such measurements? The authors further contend that most of the facilities are located in the 12 metropolitan areas surveyed. We further acknowledge that the results are constrained by the cities used. The discussant shows his research naiveté with his concern of having barely more than a 50 percent response. It should be noted that survey findings were critically reviewed for bias through plots of frequency distributions on various data items.

There was a valid basis for estimating parking demand and omitting nonparkers from the model. The comment—"Such an omission can greatly reduce the validity of an estimation model and related procedures, for line-haul riders arriving by means other than 1 person-1 car can account for significantly more riders than facility users"—is irrelevant on the condition that the research was attempting to predict only parkers, not riders of the transit in total.

The authors would acknowledge that corridors in metropolitan areas are different and that, if a model were to be developed for the city of Rochester, it might be appropriate to deal with those differences. It was not the research objective to be that specific.

The last two items of the discussion further emphasize a lack of research understanding. To include in the model for general application factors such as perceived cost or perceived convenience fails to recognize the great variability in such factors among users but also within users at various periods of the day. Our model is certainly not intended to predict the number of park-and-ride stalls required for those persons who perceive an out-of-pocket cost of 12½ cents and an arrival time of 3 min early.

We thank the discussant for the effort expended and the opportunity of further clarifying the research objectives.