PREDICTING PARK 'N RIDE PARKING DEMAND

DECEMBER 1972 - NUMBER 50

BY

U. R. ABDUS - SAMAD

W. L. GRECCO

JHRP

JOINT HIGHWAY RESEARCH PROJECT

PURDUE UNIVERSITY AND

INDIANA STATE HIGHWAY COMMISSION

Technical Paper

PREDICTING PARK 'N RIDE PARKING DEMAND

TO: J. F. McLaughlin, Director
Joint Highway Research Project

December 28, 1972

Project: C-36-74C

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 3-9-3

The attached Technical Paper "Predicting Park 'N Ride Parking Demand" by U. R. Abdus-Samad, Graduate Instructor in Research on our staff and Professor W. L. Grecco has been accepted for presentation at the 1973 Annual Meeting of the Highway Research Board in January.

The Paper is from a Final Report presented earlier as an Informational Report to the Board. It is presented in this Paper form as a good summary of the Final Report for the information of the Board Members. As this research was financed by funds granted by the General Electric Company no action on the Paper is required.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:ms

cc: W. L. Dolch
R. L. Eskew
W. H. Goetz
M. J. Gutzwiller
G. K. Hallock
R. H. Harrell
M. L. Hayes
C. W. Lovell
G. W. Marks
R. D. Miles
J. W. Miller
G. T. Satterly
C. F. Scholer
M. B. Scott
J. A. Spooner
N. W. Steinkamp
H. R. J. Walsh
E. J. Yoder

NOT FOR PUBLICATION

Technical Paper

PREDICTING PARK 'N RIDE PARKING DEMAND

by

U. R. Abdus-Samad
Formerly Graduate Instructor

and

William L. Grecco
Research Engineer

This Copy of This Report Provided By

Joint Highway Research Project

Project No.: C-36-74C

File No.: 3-9-3

The research reported herein was made possible
by funds made available to the School of Civil Engineering
by the General Electric Corporation

Purdue University
West Lafayette, Indiana
December 28, 1972

PREDICTING PARK 'N RIDE
PARKING DEMAND

U. R. Abdus-Samad, Former Graduate Instructor, Joint Highway Research Project, Purdue University, and

W. L. Grecco, Research Engineer, Joint Highway Research Project, Purdue University.

INFORMATIVE ABSTRACT

This study is concerned with the determination of design criteria for prediction of success and parking demand at park 'n ride facilities in medium to large U. S. cities.

Ninety-three change of mode parking facilities in ten different 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 covering 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.

INTRODUCTION

Transportation engineers, with 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 interface connection between the different modes qualifies as a coordinated transportation system. Change of mode parking facilities, also known as park 'n ride lots, perform the role of a connecting link between passenger car and mass transit. The passenger car is used in the collection of the trips in areas of low density trip ends. At the same time, change of mode parking increases the demand for mass transit along established travel corridors, by increasing the service area of transit stations. Finally, change of mode parking reduces the demand for parking in downtown areas, by diverting such demand to locations of lower land use density and lower land value.

Purpose and Scope

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

The second objective is to predict the demand for change of mode. This is 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, in addition to satisfying all statistical constraints. The equation in question must also be easily applied.

DATA COLLECTION

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

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 is concerned with measuring the demand placed upon change of mode facilities. The questionnaire is found in the Appendix. The measurement of change of mode demand includes the determination of the number of park 'n ride vehicles, kiss 'n ride vehicles, and change of mode passengers that use the parking facility per day. An average weekday demand is sought. Variations which occur in the demand include yearly, daily and peak hour versus non-peak. Overflow of parking lots takes place, and a knowledge of the extent of this overflow is needed to determine the actual demand for change of mode.

The demand for change of mode parking depends upon the characteristics of the transit serving the facility, such as the type of transit, headways, fares, travel times and the adequacy of the distribution network at the downtown end of the trip.

The third part of the questionnaire concerns itself with measuring the physical characteristics of the parking lot. 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 operational characteristics were to be provided by the fourth part of the questionnaire. Respondents were asked to reply to queries regarding the presence and magnitude of kiss 'n ride stalls, feeder bus berths, and attendants. They were also asked questions concerning the extent of the parking service, such as the number of hours within a day and the number of days within a week. The size of the facility, the parking fee charged, and the quality of maintenance were measured.

Part five of the questionnaire measured the location of the change of mode facilities within the metropolitan area. The type of surrounding land use, the distance to downtown and the location with respect to competitive facilities and transit fare zones were among the requested information. The proximity to, the visibility from, and the type of highway access were also considered to be relevant measures of location.

Response to Survey

A total of 357 questionnaires were mailed to 60 different 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. A total of 26 agencies replied, and gave information concerning 73 rail change of mode facilities plus 20 bus facilities. As a result of the survey, 190 usable observations are made.

Table 1 presents the response to the survey, and gives the number of observations desired and obtained, by metropolitan area and type of transit. Table 2 gives a breakdown of the survey by usability of the response, and Table 3 gives the average number of observations per facility.

Development of Aggregate Variables

The purpose of the collected data being the analysis of change of mode demand, requires that a minimum of variables be used so as to maximize the significance and reliability

TABLE 1. SUMMARY OF RESPONSE TO SURVEY

Metro-politan Area	Mailed Question-naires		Unreturned Question-naires		Returned Question-naires		Unusable Question-naires		Usable Question-naires	
	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. PERCENT BREAKDOWN OF RESPONSE TO SURVEY QUESTIONNAIRES

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

TABLE 3. NUMBER OF QUESTIONNAIRES PER CHANGE OF MODE FACILITY

	Mailed	Usable
Bus	2.03	1.81
Rail	2.12	2.09
Average	2.10	2.03

of the statistical analysis. Therefore, the need for combining the many data items into more representative and comprehensive variables is evident.

Basic Concepts

Two classes of aggregate variables are developed. The first type comprises all data items that are independent of the characteristics of parking lots. The variables thus constituted are considered to behave as parameters when parking lot demand is predicted. Three aggregate variables are created to fall into this category: (a) Transit Service rating, (b) Metropolitan Area rating, and (c) Parking Facility Location rating.

The variables that measure the parking lot characteristics make up the second class. Successful change of mode design criteria could be developed by finding those values of this class which optimize the savings that accrue to the community. Five such variables which were developed are (a) Facility Safety rating, (b) rating for Physical Quality of Facility, (c) Facility Reliability rating, (d) Facility Flexibility rating, and (e) Facility Parking Fee rating.

Each aggregate variable is made up of a combination of data items (factors). Once an item is included in the formulation of a variable it does not enter in the formulation of any other. Data items are 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 is 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 make up a given aggregate variable is attached an average rate that measures 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, at this stage, that there is no need to worry about the relative importance of variables, since an additive regression model is eventually developed.

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

In this manner many qualitative (discrete) and quantitative (continuous) factors are combined in order 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 is based on subjective engineering judgement. This judgement is based on an exhaustive evaluation of the previous literature in the field of modal split, and from a study of commuter decision making considerations.

In the case of a variable that measures some of the characteristics of a parking facility, it is necessary to be able to obtain a unique solution 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 is found, then it would be possible to determine all the associated parking lot characteristics. The lot characteristics thus determined are the design criteria for which we are searching.

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 involves the combination of factors by both addition and multiplication, and comprises 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 a measure 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 three factors.

The transit service rating is given by equation 1:

(1) Transit Service Rating = (station terminal bldg. + transit fare) + (transit speed x transit flexibility)

The above equation implies the following:

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

b. The commuter 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 seven factors that combine to describe the transit service are each subdivided into discrete levels. A rate is assigned to portray the influence of every level in the commuter's decision making process. These levels and their associated rates, which are given in Table 4, require the following remarks:

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

2. 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 above stated rate assignment takes this 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

TABLE 4. TRANSIT SERVICE RATING*

Quality of Transit Station Terminal		Transit Fare to CBD		Transit Over All Speed	
Levels	Rate	Levels (¢/mile)	Rate	Levels (mph)	Rate
Transportation Center with extra services	10	4 & below	5	30 & above	24
Luxurious	7	$4<f\leq6$	4	$20\leq s<30$	15
Adequate	4	$6<f\leq10$	3	$15\leq s<20$	9
Shelter	2	$10<f\leq20$	2	$10\leq s<15$	6
None	1	Above 20	1	Below 10	3

Proportion of CBD Jobs Reached by Transit		Availability and Cost of Transfers Within Transit		Transit Fare Zones (More Than One)		Ticket Marketing and Collection Methods	
Levels	Rate	Levels	Rate	Levels	Rate	Level	Rate
High	4	Available, 10¢ and less	1	Yes	1	Innovative	2
Average	2	Not available, or available & more than 10¢	0	No	0	Good	1
Low	1					Adequate	0

*Transit Service rating = (station terminal bldg + Transit fare) + (Transit Speed x Transit flexibility) 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, since the transit service rating would be unchanged.

3. The transit service improves with (a) an increase in the quality of the station terminal, (b) a decrease in the transit fare, (c) an increase in overall transit travel speed, (d) an increase in the proportion of CBD jobs easily reached by transit, (e) the availability of low cost transfers, (f) the existence of more than one fare zone, and (g) 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:

1. An adequate transit station terminal at the change of mode lot.
2. A transit fare of forty cents (the station is six miles from the central business district). The fare is therefore 6.67 cents/mile.
3. A transit travel time from station to downtown of 16 minutes, with a peak headway of 5 minutes. The overall travel speed is thus 19.5 miles/hour.
4. The transit distribution network in the downtown area easily reaches a low proportion of jobs.

5. Transfers are not available within the transit system.
6. The transit system has two fare zones.
7. The transit system possesses good ticket marketing and collection methods.

Using Table 4, one reads the following rates: 4, 3, 9, 1, 0, 1, 1. Combining these rates according to equation 1, we get:

Transit Service rating = 4+3+9x(1+0+1+1) = 34

Seven factors were combined to obtain an integer valued variable which will be used to predict change of mode parking demand. The reader is referred to Tables 5-12, and Figure 1 for the methods used in developing the remaining aggregate variables (i.e.: the factors involved in each variable, the levels and associated rates for each factor, and the equations used to combine factors into aggregate variables). Table 13 summarizes the results of the modeling technique.

PARKING LOT USAGE

This section reports on the procedure employed and the findings of the analysis of variance, regarding the effect of the aggregate variables (see previous section) on change of mode parking lot usage. The analysis of variance is based on 190 observations made over 93 facilities in ten different metropolitan areas.

TABLE 5. METROPOLITAN AREA RATING*

Representative Transit Speed In Metropolitan Area		Condition of Parking In CBD		Distance From CBD Where Heavy Congestion Starts		Metropolitan Area Population	
Levels(mph)	Rate	Levels	Rate	Levels(mi.)	Rate	Levels (10^6 persons)	Rate
$20<s$	10	Intolerable	5	$8<d$	8	$2.5<p$	9
$15<s\leq 20$	6	Problematic	3	$5<d\leq 8$	6	$1.0<p\leq 2.5$	6
$10<s\leq 15$	4	Worrisome	2	$3<d\leq 5$	4	$0.5<p\leq 1.0$	3
$s\leq 10$	2	No Worry	1	$d\leq 3$	2	$p\leq 0.5$	1

*Metropolitan area rating = Transit speed + CBD parking congestion

+ Radial highway congestion

+ Metropolitan area population

TABLE 6. FACILITY LOCATION RATING*

Distance to Lower Fare Zone		Distance to Nearest Competitive Facility		Distance to Highway Access		Width of Highway Access	
Levels(mi.)	Rate	Levels(mi.)	Rate	Levels(blocks)	Rate	Levels(lanes)	Rate
None or 5<d	5	None or 5<d	3	d<2	3	L>4	6
2<d≤5	3	2<d≤5	2	2≤d<5	2	L=4	3
1<d≤2	1	1<d≤2	1	5≤d	1	L<4	1
d≤1	0	d≤1	0				

*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)

TABLE 6. Cont.

Visibility of Facility From Access		Distance From Facility to CBD		Surrounding Land Use Type		Surrounding* Residential Density	
Levels	Rate	Levels(mi.)	Rate	Levels	Rate	Levels$(\frac{10^3 per.}{sq.mi.})$	Rate
Quite Visible	3	$16<d$	10	Residential	6	$22<d$	7
Slightly Visible	2	$12<d\leq16$	8	Res'l-Com'l	4	$16<d\leq22$	5
Info. Signs are posted	1	$8<d\leq12$	6	Commercial	3	$10<d\leq16$	3
Not Visible	0	$4<d\leq8$	4	Res'l-Ind'l	2	$4<d\leq10$	1
		$2<d\leq4$	2	Res'l-Ind'l-Com'l	1	$d\leq4$	0
		$d\leq2$	0	Industrial	0		

*See Figure 1

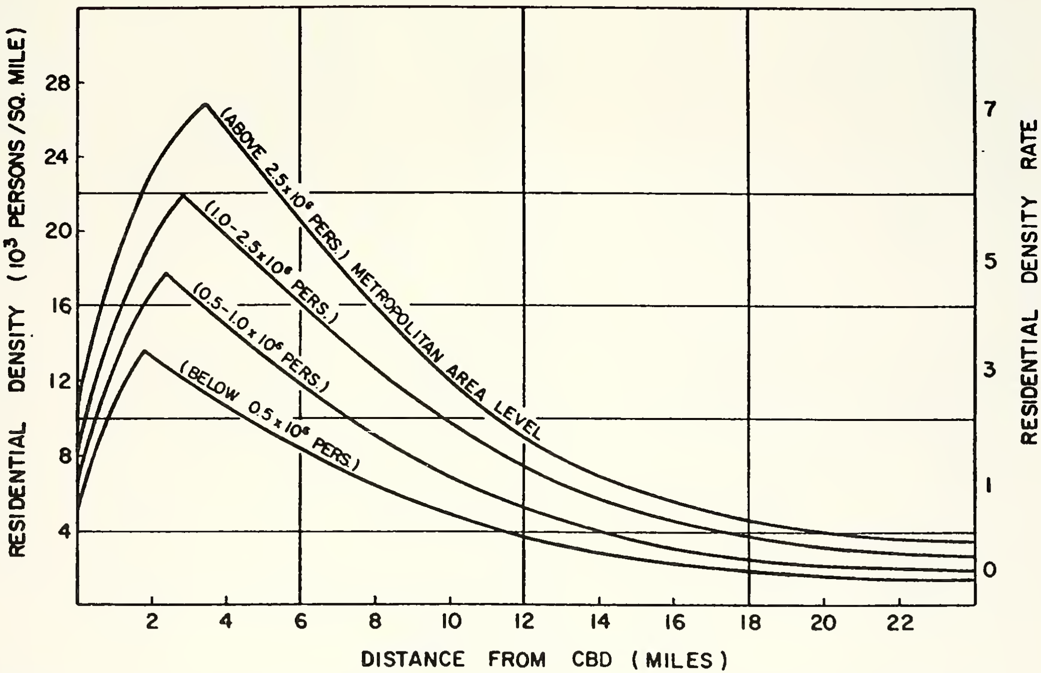

FIGURE 1 RESIDENTIAL DENSITY AS A FUNCTION OF LOCATION WITHIN CITY, AND METROPOLITAN SIZE LEVEL

TABLE 7. FACILITY SAFETY RATING*

Condition of Lighting In Facility		Availability of Enclosures And Number Of Gates	
Levels	Rate	Levels, $g = (\frac{gates}{200\ stalls})$	Rate
Good	3	Yes, $g>1$	3
Poor	2	Yes, $g\leq 1$	2
Fair	1	Fairly enclosed	1
None	0	None	0

TABLE 8. PHYSICAL QUALITY RATING OF FACILITY**

Pavement Type of Facility		Average Walking Distance From Facility to Station	
Levels	Rate	Levels (feet)	Rate
Paved, Marking & Landscaping	8	$d<300$	4
Paved & Marking	6	$300\leq d<500$	3
Treated Surface	4	$500\leq d<700$	2
Gravel	2	$700\leq d$	1

* Facility Safety rating = Facility lighting + Availability of Enclosures

**Physical Quality rating = Pavement type + Walking distance

TABLE 9. RATING OF FACILITY FLEXIBILITY*

Agency Type of Facility Owner		Agency Type of Facility Operator	
Levels	Rate	Levels	Rate
Transportation and/or Planning either public or private	2	Same as Transit Operator	2
Other	1	Different from Transit Operator	0

Proportion of Kiss & Ride Stalls to Total Stalls in Facility		Availability of Connecting Bus Lines	
Levels (percent)	Rate	Levels	Rate
$6.00<p$	8	Yes	10
$3.00<p\leq 6.00$	4.5	No	0
$1.00<p\leq 3.00$	2.0		
$0.00<p\leq 1.00$	0.5		
$p=0.00$	0.0		

*Flexibility rating = (Agency type of owner x Agency type of operator) + Availability of bus berths + Proportion of kiss 'n ride stalls

TABLE 10. RATING OF FACILITY RELIABILITY*

Days of Facility Operation		Hours of Facility Operation		Availability and Number of Attendants		Maintenance Quality	
Levels (Days/week)	Rate	Levels (hr/day)	Rate	Levels $(\frac{\text{attendants}}{\text{200 stalls}})$	Rate	Levels	Rate
$d=7$	2.0	$20<h$	2.0	Yes, $1.5<a$	10	Good	5.0
$d=6$	1.0	$12\leqslant h\leqslant 20$	1.0	Yes, $0.5<a\leqslant 1.5$	5	Adequate	2.5
$d\leqslant 5$	0.4	$h<12$	0.4	Yes, $a\leqslant 0.5$	2	Poor	1.0
				No	0	None	0

*Reliability rating = Days of operation + hours of operation + Availability of attendants + Maintenance quality

TABLE 11. RATING OF FACILITY PARKING FEE

Facility Parking Fee	
Level ($/day)	Rate
f=0.00	6
0.00<f≤0.20	4
0.20<f≤0.50	3
0.50<f≤1.00	2
1.00<f	1

TABLE 12. RATING FOR YEARS FROM START

(Polling Date - Start of Operation Date)	
Levels (years)	Rate
y≤1	0
2≤y≤6	1
7≤y	2

TABLE 13. DATA SUMMARY OF AGGREGATE VARIABLES

Variable	Theoretical Range		Sample Range		Sample Average	
	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

Analysis of Variance

The object of the statistical analysis is to study the trends and significance of the effects of the parametric and design variables on the percent usage of change of mode parking lots. It should be understood that the percent usage of a lot measures the success of a lot 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 14 and 15 give the results of all 28 ANOVA tables. Table 14 deals with the main effects of the ratings and the variables are the same as those spelled out in Table 13. The values given in both tables are the ratios of the computed F's by 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 non-significance is rejected. When the ratio between F's is smaller than one, then the hypothesis of non-significance cannot be rejected.

As a result of the analysis of variance, the following conclusions are taken (refer to Tables 14 and 15):

1. The main effects of the metropolitan area rating are significant in all of the seven cases in which they appear. The same applies in the case of the

TABLE 14. RATIO OF COMPUTED BY CRITICAL F, FOR MAIN EFFECTS OF RATINGS

		Variable							
		T	M	L	S	Q	F	R	P
Associated Variable	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 15. RATIO OF COMPUTED BY CRITICAL F, FOR INTERACTIONS BETWEEN RATINGS

		First Variable							
		T	M	L	S	Q	F	R	P
Second Variable	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	

facility safety and the facility reliability ratings. The three above mentioned ratings are factors that do affect the usage of change of mode parking lots.

2. The main effects of the facility location rating are found to be always not significant. Four possible reasons could explain this finding. First, the modeling of the location rating could be inadequate; or second, the location rating interacts to a high degree with other factors; or third, the location rating truly does not affect the usage of parking facilities; or finally, and most likely, a high percentage of the transit facilities reporting had very good locational characteristics, which provides low variation in the location rating. Variables with low variation are generally found non-significant.
3. The main effects of the remaining ratings (transit service, physical quality, flexibility, parking fee) are found to be significant in more than half of the cases in which they are involved. The data seems to suggest that the four factors significantly affect the usage of change of mode parking facilities.
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 percent usage of parking facilities. These

findings seem to indicate that the extent to which a facility is used is based on combining the three mentioned factors with the design ratings (safety, quality, flexibility, 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 'N 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 to assume an additive model. Therefore, one should view the linear equation as only an estimate or an approximation until such time as further evidence is available.

A regression equation was developed to predict the number of park 'n ride vehicles. The equation was later tested to see if 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 χ^2 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 'n 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 2 is the chosen prediction equation:

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

where

D = number of park 'n ride vehicles that use a facility during a 24 hour period,

Z = total 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, rail and bus on exclusive right of way = 1),

R = reliability rating of the change of mode parking facility (see Table 10),

T = transit service rating at the change of mode parking facility (see Table 4),

M = metropolitan area rating for the change of mode parking facility (see Table 5),

F = flexibility rating of the change of mode facility (see Table 9),

P = parking fee rating of the change of mode facility (see Table 11).

Table 16 summarizes the statistical qualities of the chosen prediction equation. Equation 2 explains 78 percent of the variation in the park 'n ride demand, and has a multiple correlation coefficient R = 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 9995 in ten thousand. 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 per day.

The chosen equation was tested for homogeneity of variance using the Bartlett test. A χ^2 equal to 5.81 was obtained with four degrees of freedom. Since the critical χ^2 at the ten percent level (7.78) is larger than the computed one, the hypothesis of homogeneity of variance and normality of the error term is accepted.

TABLE 16. STATISTICAL QUALITIES OF PREDICTION EQUATION

Step Number	Variable Name	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

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 'n 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 regression equation's ability to predict the park 'n ride demand seems appropriate. For this purpose, the data from the Institute of Traffic Engineers' survey are used to test whether or not the prediction equation does a good job of predicting the number of parked vehicles at a change of mode lot. Out of the 179 facilities that the ITE surveyed only nine were used. All the remaining 170 facilities either coincided with data collected and previously used in developing the equation, didn't 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 two different methods. The first test was on the hypothesis that the mean difference between estimated and measured park 'n ride demand is equal to zero. The Student-t test was used to either accept or reject the hypothesis. Table 17 gives the observed and estimated park 'n ride demand for the nine checked facilities, and the difference between. A Student-t of 0.91 was

TABLE 17. OBSERVED AND ESTIMATED PARK 'N RIDE DEMAND
(P.C. - PASSENGER CARS)

Observed Demand		Estimated Demand		Difference
$(P.C./day)^{1/2}$	P.C./day	$(P.C./day)^{1/2}$	P.C./day	
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

computed using the paired comparison difference between observed and estimated park 'n ride 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 eight degrees of freedom is equal to 1.40 which is much larger than the computed one. Since the hypothesis is accepted even at an α equal to 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 is developed for the observed demand, with the estimated demand being the sole independent variable. If the individual estimates are equal to the corresponding observed demand, then the equation would have a zero intercept ($b_o = 0$), and a slope of 45 degrees ($b_1 = 1$). An F-ratio was used to test the hypothesis that the regression equation for the estimated versus observed demand possesses a b_o and a b_1 coefficients that are equal to zero and one 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 satisfies the statistical constraints that are inherent in a linear regression model has been developed. This equation is also able to reliably predict the park 'n ride demand at different facilities and in different metropolitan areas.

CONCLUSIONS

Statistical evidence indicates that most of the developed characteristics' ratings 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 usage of parking facilities.

A study of the park 'n 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 'n 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 'n 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 six 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 ofthe 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.

ACKNOWLEDGEMENT

The authors wish to acknowledge the funding of this project by the General Electric Corporation and data assistance provided by the change of mode parking facility operators and the Institute of Traffic Engineers.

APPENDIX

SURVEY QUESTIONNAIRE

QUESTIONNAIRE

CHANGE OF MODE PARKING FACILITIES

Name of Facility ________	Name: ________
Name of Metropolitan Area ________	Position: ________
Name of Political Jurisdiction in which facility is located ________	Address: ________
	Date: ________

A-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 stuo?	________ (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 ________ %

B. TRANSIT SERVICE

1. What is the type of the transit system being served by parking facility?	○ ..... bus ○ ..... 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?	○ ....high ○ ..... average ○ ....low

C. 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

D-OPERATIONAL CHARACTERISTICS

1. Does the facility include any kiss & ride stalls? If answer is yes, please give number.	O..... yes O...... 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.	O..... yes O...... 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?	O..... Good O..... Adequate O..... Poor O......... 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.	O..... yes O..... no ______ attendents
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.	O..... yes O..... no ______ ______

E-LOCATION OF FACILITY

1. What is the major land use type in which the parking facility is located?	O..... Res'l O.......... Ind'l O..... Res+Ind O......... Rs+Com O..... Comm'l O..... 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

F-GENERALITIES

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