SENSITIVITY ANALYSIS OF COMMUNITY SAVINGS DUE TO CHANGE-OF-MODE OPERATIONS

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This study is concerned with a sensitivity analysis of the community savings provided by successful change-of-mode (park-and-ride) facilities in medium to large U.S. cities. The research was an early attempt to generalize the locational aspects of change-of-mode facilities and their benefits to the community. The determination of the community savings due to the diversion of trips from highway to change-of-mode facilities is a prerequisite in assessing the feasibility (success of park-and-ride facilities). Community savings (the summation of both user and nonuser benefits) are computed as the difference in travel costs by highway alone and or by change-of-mode facilities. Travel costs are simulated in a deterministic fashion and by using average unit costs for cities of different sizes and for different locations within a given city. The simulated community savings data are then used to develop a linear multiple regression equation to predict the savings.

•A BALANCED transportation system uses each different transportation mode where it is most efficient and provides for a smooth interface connection among the different modes. Efficiency and coordination are some of the prerequisites for good transportation planning. Change-of-mode parking facilities, also known as park-and-ride lots, perform the role of a connecting link between passenger car and public transit. The passenger car is best 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 public transit along established travel corridors by extending the service area of transit stations. Change-of-mode parking reduces the demand for parking in downtown (CBD) areas by diverting such demand to locations of lower land use density and lower land value. Downtown space is too valuable for the long-term storage of the work-trip vehicle. Finally, the public concern for energy conservation should provide a higher acceptance of change-of-mode operations than of full transit service.

The objective of the study is to determine the economic feasibility of change-of-mode parking facilities. Only the benefits (community savings) are reported on. For this purpose, a linear multiple regression is developed to estimate the community savings due to change-of-mode in different size U.S. cities and for different locations within a given city.

Savings are defined as both user and nonuser benefits although most of the community savings are due to savings accruing to change-of-mode users. Differential land productivities and pollutant emissions savings are the only real nonuser economic factors. Social savings and savings to highway users from the diversion of some of the users to change-of-mode are not computed or used, since it is felt that such savings are small because of the relative insignificance of change-of-mode effects on existing travel patterns. For simplification, only first-order benefits and costs are quantified. For example, the study ignored the increased efficiency of the workers due to the ease of travel by transit for the congested portion of the work trip.

TRAVEL COSTS

The travel costs based on the passenger car are vehicle operation, accidents, and pollution. The transit fare is the only cost used for travel by transit. Emphasis was placed on easily quantified, first-order factors. The researchers ignored the subsidies received by both transit and the private automobile industry. An example of the latter would be the extensive oil depletion allowance that is reflected in lower fuel costs. The units for travel costs by passenger car are in dollars per vehicle mile (kilometer). The units for travel costs by transit are in dollars per passenger-mile (kilometer). There are also other cost elements that enter in the analysis of commuter savings, and these will be discussed later.

Although a generalized model is the objective, some categorization is used to reduce the variance of the developed model. Driving conditions change with the type of highway being used; therefore, unit travel costs are developed by highway type. For this same purpose, the street network is subdivided into four types: expressways, arterials, local streets, and downtown streets. Table 1 gives the unit costs used (in 1970 dollars) for travel by passenger car (1, 2, 3, 4, 5, 6, 7).

Vehicle operating costs that are computed as time costs include licenses, depreciation, vestcharge (1, p. 71), insurance, parking, tolls, and taxes. Oil, gasoline, maintenance, and tires were expressed as mileage items (Table 2). Differences in travel speed and the frequency of stops are the two elements of driving conditions that affect the vehicle operating costs.

Pollution costs are computed on the basis of cost estimates for proposed exhaust control devices (Table 3, Figure 1). It is expected that damage costs from automobile emissions are larger than the control costs used here. The difficulty of establishing the true costs of pollution, such as health, cleaning bills, and house painting, necessitates extensive data collection. Unit accident costs used include all types of accidents (fatal, injury, property damage) and are computed for passenger cars in urban areas (Table 3). Unit accident costs are based on $4,670/average accident.

Transit fare costs are based on existing fares in Cleveland (rail) and Milwaukee (bus) and on the proposed fares for San Francisco (rail) (8, 9, 10). Equation 1 is developed to estimate transit fares in dollars per passenger-mile (kilometer) (Figure 2).

$$\text{Transit fare} = 0.20\ (\text{transit trip length})^{-0.646} \tag{1}$$

Equation 1 is expressed in terms of 1970 dollars, and the transit trip length is in miles (kilometers).

RELATED COSTS

The related costs are those that account for travel time, land productivity, and parking fees. Since change-of-mode trips are work trips, one should account for the cost of time. When a parcel of land is used as a parking lot or for a parking garage, a land productivity loss occurs since the land could have been used for more productive purposes. The vehicle storage area is transferred out to lower valued land on the periphery.

The value of time for work trips is assumed to be equal to $1.25/person hour (11). Based on inflation occurring since 1970, any selected value of time would be suspect. Assuming average travel speeds and average car occupancy, the travel time cost in dollars per vehicle mile (kilometer) becomes equal to 0.187 for CBD streets, 0.100 for local streets, 0.081 for arterials, and 0.046 for expressways (3, 12, 13) (Table 3).

Similarly, the cost of time for travel by transit in dollars per passenger-mile (kilometer) is equal to 0.059 for express bus and 0.042 for rapid transit (3, 8, 9, 13) (Table 4). Time is also spent at both ends of a trip. This terminal time is assumed to be equal to

Table 1. Unit travel costs for passenger cars.

Highway Type	Vehicle Operation[a]	Pollution[a]	Accidents[a]
CBD streets	0.143	0.023	0.007
Local streets	0.128	0.015	0.007
Arterials	0.123	0.012	0.005
Expressways	0.113	0.006	0.002

Note: 1 mile = 1.6 km.

[a]All values are in dollars/vehicle mile (kilometer).

Table 2. Cost items for vehicular operation.

Item	Cost ($/vehicle mile)	Item	Cost ($/vehicle mile)
Time		Mileage	
Licenses, depreciation, and vestcharge	0.0339	Engine oil	0.0016
Insurance	0.0172	Gasoline	0.0253
Garage, parking, and tolls	0.0180	Maintenance	0.0155
Property taxes	0.0033	Tires	0.0041
Total	0.0724	Total	0.0465

Note: 1 mile = 1.6 km.

Figure 1. Control cost of probable reduction in emission of pollutants.

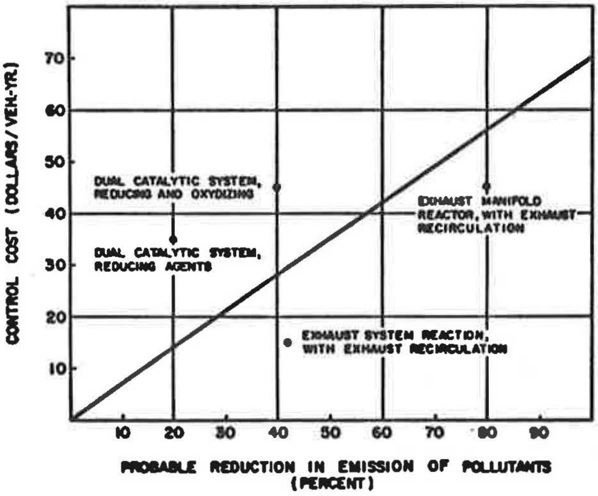


Table 3. Pollutant emissions, accident rates, and travel speeds, by highway type.

Highway Type	Emissions (lb/vehicle mile)	Accident Rate (per 10^8 vehicle miles)	Travel Speed (mph)
CBD streets	0.545	493	8
Local streets	0.355	513	15
Arterials	0.292	340	19
Expressways	0.152	160	32

Note: 1 lb = 0.45 kg. 1 mile = 1.6 km.

Figure 2. Transit fare to and from CBD.

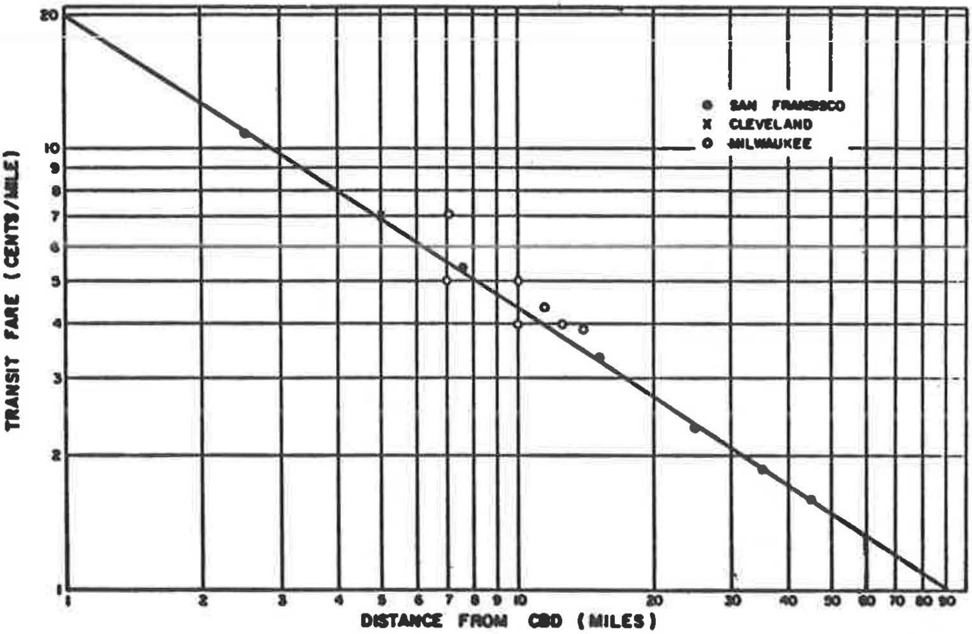
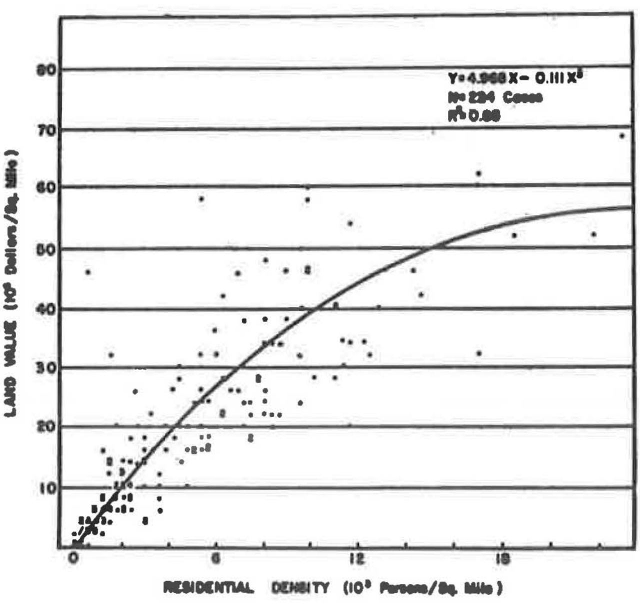


Table 4. Public transit travel speeds and terminal time costs.

Item	Average Travel Speed (mph)	One-Way Terminal Time ($/commuter)
New rapid rail	38	
Kiss-and-ride		0.135
Park-and-ride		0.156
Express bus	21	
Kiss-and-ride		0.208
Park-and-ride		0.229

Note: 1 mile = 1.6 km.

Figure 3. Land value versus residential density.



7 min/person for a one-way trip by passenger car (14), 6.5 and 10.0 min/person for a one-way kiss-and-ride trip by rail and bus respectively, and 7.5 and 11.0 min/person for a one-way park-and-ride trip by rail and bus respectively (Table 4).

The loss of land productivity is assumed to be equal to 10 percent of the land value. In 1970, it was still reasonable to expect rental properties in the CBD to provide an annual net return of 10 percent of the property value. Figures 3, 4, and 5 are used to determine the land value for a change-of-mode lot in different size cities. The land value of downtown parking is assumed to be equal to $2,000/stall, based on some economical number of garage floors (15).

Parking fees in the CBD are computed on the basis of existing rates and adjusted to 1970 dollars (15). Equation 2 is developed to estimate parking fees in the downtown of metropolitan areas in dollars per vehicle (Figure 6). This estimate only applies to work trips.

$$\text{Downtown parking fee} = 0.84 \log \frac{(\text{metropolitan area population})}{34} \quad (2)$$

The metropolitan area population is in thousands of persons.

All of the related costs are expressed in terms of 1970 dollars. It is important to note that highway and transit construction and operation costs are not to be included in the analysis of commuter and community savings from change-of-mode facilities. The purpose of the analysis is to assess the feasibility of change-of-mode facilities and not to compare public transit and highway.

COMMUNITY SAVINGS

Community savings (both user and nonuser) are defined as the difference in total costs between driving all the way to the CBD and driving to a change-of-mode parking lot and taking transit for the remaining part of the trip. A trip is defined as a two-way trip, from home to work and work to home.

Simulation Program

A computer program was written in FORTRAN IV to deterministically simulate the community savings based on the average trends already reported.[1] A total of 1,008 different conditions are generated in a factorial design for which community savings are computed. The savings are analyzed for a factorial combination of six populations of metropolitan areas (0.5 to 7 million persons), seven distances of the parking lot to the CBD [1 to 20 miles (1.6 to 32 km)], two types of transit (bus and rail), four ratios of kiss-and-ride stalls to total stalls (1 to 15 percent), and three distances of the parking lot to the street access (2 to 8 blocks).

The simulation program computes the cost of traveling by passenger car to the CBD and the cost of traveling by passenger car to a change-of-mode lot and taking public transit to the CBD. The two travel alternatives are shown in Figure 7. The elements of cost for a trip by passenger car to the CBD are

1. Vehicle operation,
2. Vehicle emissions,
3. Vehicle accidents,

[1] A copy of the program is in an appendix that is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-62, TRR 557.

Figure 4. Variation of land value with distance from highway.

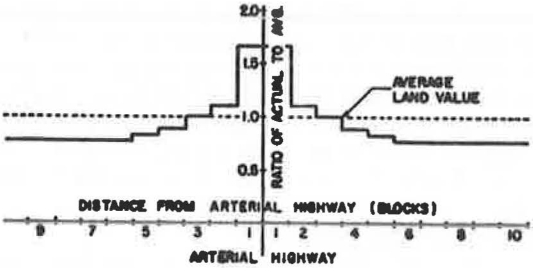


Figure 5. Residential density as function of location within city and metropolitan area size.

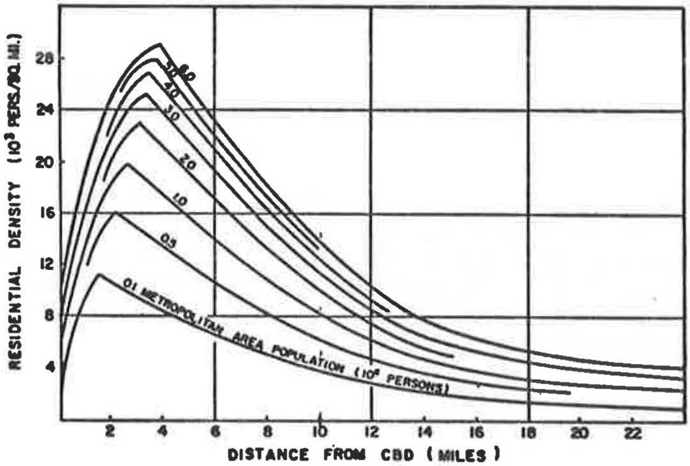


Figure 6. Variation of CBD parking fee with metropolitan area size.

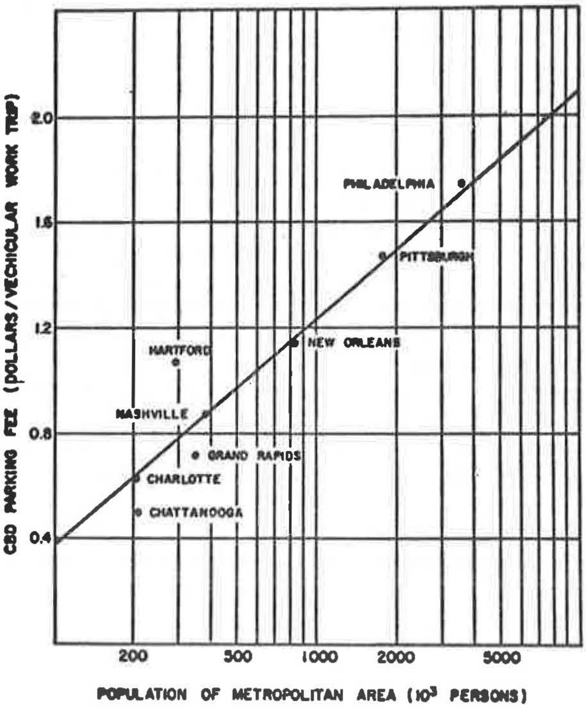


Figure 7. Change-of-mode process.

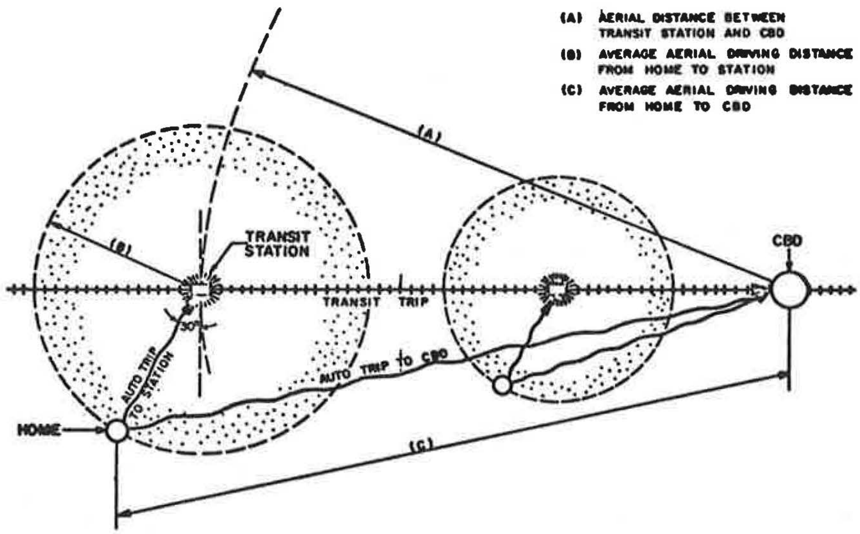
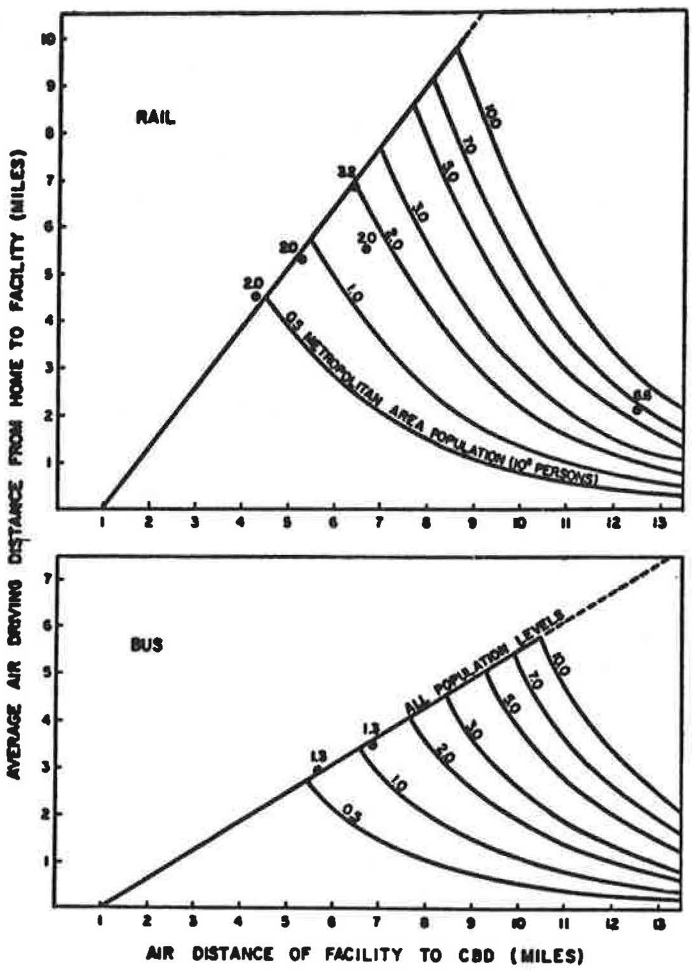


Figure 8. Average driving distance from home to change-of-mode parking lot.



4. Travel time,
5. Terminal time,
6. CBD parking fee, and
7. Loss of land productivity in downtown.

The elements of cost for a change-of-mode trip to the CBD are

1. Vehicle operation for automobile portion of the trip,
2. Vehicle emissions for automobile portion of the trip,
3. Vehicle accidents for automobile portion of the trip,
4. Travel time for automobile portion of the trip,
5. Total terminal time,
6. Travel time for transit portion of the trip,
7. Transit fare, and
8. Loss of land productivity due to change-of-mode lot.

A number of cost elements have been developed based on vehicle miles (kilometers) or passenger-miles (kilometers). Since actual costs are to be determined for a trip, the need for estimating trip lengths is apparent. Figure 8 shows the average airline distance from a commuter's home to a change-of-mode lot as a function of the airline distance of the change-of-mode lot to the CBD and the size of the metropolitan area. This figure was developed from the results of surveys conducted in Cleveland, Milwaukee, Boston, and Chicago (8, 9, 16, 17, 18). Airline distances were transformed to over-the-road distances for the purposes of simulation. As shown in Figure 8, the average driving distance from home to change-of-mode lot decreases beyond a given distance of change-of-mode lot to the CBD. This is due to the start of finger type of land use development along radial corridors and not to the unwillingness of commuters to drive additional distances.

Travel distances that are less than 0.4 miles (0.6 km) are made on local and downtown streets. Travel distances in excess of 1.9 miles (3 km) are made on expressways. The balance between 0.4 and 1.9 miles (0.6 and 3 km) is the distance driven on arterials (19).

The community savings are computed in dollars per park-and-ride vehicle per day. In order to accomplish this, cost units are transformed from dollars per vehicle mile (kilometer) and dollars per passenger-mile (kilometer). The key for the transformation of unit costs is the number of change-of-mode passengers (park-and-ride and kiss-and-ride) per park-and-ride vehicle. The data collected for the general purposes of the research project and used for estimating the demand at change-of-mode parking lots (20) were the basis for developing a multiple regression equation to estimate the number of park-and-ride vehicles that use a facility during a 24-hour period, D.

$$\sqrt{D} = -0.705 + 0.009\,Z + 1.964\,B + 1.211\,R + 001\,T^2 + 0.009\,M^2 + 0.049\,F \cdot P - 0.019\,T \cdot R \qquad (3)$$

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 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.

The R^2 for equation 3 is 0.78. Measures of the variables that make up the ratings are detailed elsewhere (20).

A survey conducted recently by the Institute of Traffic Engineers indicated that only one-fourth to one-fifth of the demand at change-of-mode lots is actually diverted from the street network (21). The remaining portion of the demand either did not make the trip before or, as in most cases, already had changed modes but parked on streets in the vicinity of public transit stations.

Results

The simulation program generated savings data for more than a thousand different conditions of metropolitan area size, change-of-mode distance to the CBD, percentage ratio of kiss-and-ride stalls to total stalls, type of transit, and parking lot distance to the street access. These data were fed as input to a packaged step-wise linear multiple regression program; community savings (in dollars per parked vehicle per day) were the dependent variable, and the factors defining a condition were the independent variables. The results of the regression analysis are given in equation 4.

$$\begin{aligned}\text{Community savings} = {} & 0.40627 + 0.00002\,p + 0.04498\,d \\ & - 0.15028\,t - 0.00261\,k + 0.00193\,d^2 \\ & - 0.000001\,p \cdot d \end{aligned} \qquad (4)$$

where

- p = size of metropolitan area in thousands of persons,
- d = distance of change-of-mode lot to CBD in miles (kilometers),
- t = type of transit (rail = 1, bus = 2), and
- k = percentage ratio of kiss-and-ride stalls to total stalls.

The R^2 in equation 4 is 0.97, and all of its independent terms are significant at a rate higher than 9,995 in 10,000. Only the parking lot distance to the street access was found to be insignificant in affecting the community savings.

CONCLUSIONS

Under present conditions, the community savings vary from \$0 to \$2 per park-and-ride vehicle per day. Community savings increase in larger metropolitan areas for change-of-mode lots located further from the CBD and for rail transit. Community savings decrease for a higher percentage of kiss-and-ride stalls, and this is due to lower car passenger occupancy for the demand at change-of-mode lots.

The savings that accrue to a community from the use of change-of-mode parking are most sensitive to the location of the parking facility. The further from the downtown the change-of-mode takes place, the larger the unit savings are. However, under this condition, the transit service tends to decline in quality and quantity because of the diseconomy of providing the same service as that found closer to the downtown. In addition, facilities located far from the downtown are under suburban jurisdictions that do not possess and cannot raise the funds required for providing good-quality parking facilities. The park-and-ride demand is thus reduced. The combination of facts thus suggests that the total community benefits would peak at a specific distance from the downtown and would decline from there on. This observation was further substantiated by the literature (25).

ACKNOWLEDGMENT

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REFERENCES

1. R. Winfrey. Economic Analysis for Highways. International Textbook Co., Scranton, Pa., 1969.
2. Cost of Operating an Automobile. Bureau of Public Roads, U.S. Department of Transportation, 1970.
3. D. S. Berry and others. The Technology of Urban Transportation. Northwestern Univ. Press, Evanston, Ill., 1963.
4. Chicago's Crosstown Expressway. American Road Builder, Vol. 56, Jan. 1969, pp. 16-17, 22.
5. National Air Pollution Control Administration. Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emission From Vehicle Sources. National Air Pollution Control Administration, Washington, D.C., PB AP-66, 1970.
6. J. K. Kihlberg and K. J. Tharp. Accident Rates as Related to Design Elements of Rural Highways. National Cooperative Highway Research Program, Rept. 47, 1968.
7. H. L. Michael and others. The Estimated Direct Costs (1970) of Traffic Accidents on Indiana Rural State Highways. Joint Highway Research Project, Purdue Univ., Oct. 1970.
8. G. Ihnat. Cleveland Transit and Parking Operations. Highway Research Circular 91, Jan. 1969, pp. 1-28.
9. H. M. Mayer. Change of Mode Commuter Transportation in Metropolitan Milwaukee. Highway Research Circular 83, Oct. 1968, pp. 1-12.
10. Parsons, Brinckerhoff, Hall and McDonald. Regional Rapid Transit. Prepared for San Francisco Bay Area Rapid Transit Commission, Jan. 1956.
11. T. C. Thomas. The Value of Time for Passenger Cars: An Experimental Study of Commuters' Values. Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., Vol. 2, PB 175 731, May 1967.
12. J. E. Baerwald, ed. Traffic Engineering Handbook. Institute of Traffic Engineers, Washington, D.C., 3rd Ed., 1965.
13. Transportation and Parking for Tomorrow's Cities. Wilbur Smith and Associates, New Haven, Conn., 1966.
14. R. H. Burrage and others. Parking Guide for Cities. Bureau of Public Roads, Department of Commerce, 1956.
15. Parking in the City Center. Wilbur Smith and Associates, New Haven, Conn., 1965.
16. Mass Transportation in Massachusetts. Mass Transportation Commission, McKinsey and Company, Inc., and Joseph Napolitan Associates, Inc., Boston, Mass., final rept., July 1964.
17. The Skokie Swift: A Study in Urban Rapid Transit. Chicago Area Transportation Study, Chicago, Ill., July 1968.
18. Joseph Napolitan Associates, Inc. A Survey to Determine Factors Which Influence the Public's Choice of Mode of Transportation. Mass Transportation Commission, Boston, Mass., final rept., April 1964.
19. B. V. Martin and others. Principles and Techniques of Predicting Future Demand for Urban Area Transportation. M.I.T. Press, Cambridge, Mass., Rept. 3, June 1961.
20. U. R. Abdus-Samad and W. L. Grecco. Predicting Park 'n Ride Parking Demand. Highway Research Record 449, 1973, pp. 45-62.
21. S. M. Silence et al. Change of Mode Parking: A State of the Art. Institute of Traffic Engineers, Washington, D.C., 1972.

22. J. P. Pickard. Changing Urban Land Uses as Affected by Taxation. Urban Land Institute Research Monograph 6, 1962, pp. 1-105.
23. Highway and Economic and Social Changes. Office of Economic Research, Bureau of Public Roads, 1964.
24. Chicago Area Transportation Study. Chicago, Ill., Final Rept., Vol. 1, Dec. 1959.
25. D. M. Gatens. Locating and Operating Bus Rapid Transit Park-and-Ride Lots. Transportation Research Record 505, 1974, pp. 21-30.