A Model for Estimating Transit Usage In Cities in Iowa

R. L. CARSTENS, Associate Professor, and L. H. CSANYI, Professor, Department of Civil Engineering, Iowa State University

Reasonably accurate forecasts of transit patronage and revenues often are needed for solutions to urban transportation problems. This study developed a model for estimating annual totals for patronage and revenues using the following as independent variables: quantity of transit service provided, average fare, size of city, and proportion of population not in the working force.

Data utilized in developing the model were collected from 13 transit operations in Iowa covering 114 annual periods from 1955 through 1965. The model is thus applicable only for communities in Iowa, but offers an insight into factors that may be applicable generally for transit operations in small urban areas.

•PEOPLE in the United States are increasingly conscious of the role of mass transportation in urban areas. The public realizes that an efficient transit system not only helps alleviate traffic congestion but is vital to that segment of the population that has no alternate form of transportation available. Furthermore, there is growing public recognition of the need and the justification for public financial support in many cities, if this important public service is to remain available. Enactment by the U. S. Congress of the Mass Transportation Act of 1964 resulted from its concern for the problems of mass transportation and its determination to solve these problems. Local concern is evidenced by the large number of cities that have sought federal assistance under the Act.

The current problems of mass transportation result primarily from the marked changes in travel habits of urban populations. Such changes have occurred largely since World War II. During the war, patronage of transit was at an all-time high in the United States. Almost 19 billion revenue passengers were carried during 1945 (1). Also in 1945, there were 130 billion vehicle-miles of travel by motor vehicles on urban streets (2). After the removal of wartime restrictions on motor-vehicle travel, transit patronage declined rapidly. In 1950, fewer than 14 billion revenue passengers were carried on transit lines of the United States while urban motor-vehicle travel increased to 218 billion vehicle-miles. Despite the fact that urban area populations have increased markedly since 1950, transit usage has continued to decline. The trend toward suburbanization, continued economic prosperity, and the increase in automobile ownership resulting from these factors have all continued to lead to a substantial growth in motor-vehicle travel and further decline in transit patronage. During 1965, transit lines carried fewer than 6.8 billion revenue passengers (about 36 percent of the number carried in 1945) while there were 424 billion vehicle-miles of urban travel by motor vehicle (over three times that in 1945).

Cities in Iowa exhibit similar travel trends. Urban street traffic is increasing rapidly at the same time that transit patronage is decreasing. For example, the number of revenue-producing transit trips in Des Moines in 1965 was 23 percent of the number in 1950. Comparable figures were 48 percent in Dubuque and 18 percent in

Paper sponsored by Committee on Passenger Transportation Economics.

Burlington, the only other cities for which 1950 data were available for this study. The substantially reduced revenues accompanying the declines in patronage have obviously created serious financial problems for transit operators.

In 1967, 17 cities in Iowa had franchised transit service. Buses were utilized exclusively except for a cable railway in Dubuque. An indication of the financial problems encountered in several of these cities is afforded by events occurring during 1965 and 1966. During this two-year period, four cities faced abandonment of their transit operation. In all four cities, programs involving public ownership or public subsidy were adopted to prevent loss of service. Operations in two other cities were subsidized by the public prior to 1965. In most other cities, franchised transit operations are partially subsidized by earnings from school bus contracts, from charter services, or from non-transportation operations.

PURPOSE OF STUDY

This study was undertaken to gain an understanding of the characteristics of a community or of a transit operation that account for the considerable differences in transit service use among different urban areas. An understanding of these characteristics is essential to make realistic forecasts of future trends in transit usage.

Numerous other studies have been concerned with forecasts of travel mode in urban areas. These generally have produced mathematical expressions that are solved to yield a percentage of total personal travel that will utilize mass transportation. This dependent variable is referred to as the modal split. Several independent variables have been employed by various researchers. Among the most common are costs of service of competing travel modes, quality of transportation service, urban-area population, population density, automobile ownership, and several indicators of socioeconomic status. For the most part, these models were developed for application only to a tract of land within a specific area and used for assigning traffic as part of an urban transportation study.

However, modal splits for travel in cities in Iowa are very low. Nine recent comprehensive origin-destination studies made by the Iowa State Highway Commission show that from 1.5 percent to 10.7 percent of all person-trips on average weekdays were made by bus passengers. More than 6.5 percent of all person-trips were made by transit in only one city, Dubuque, and the median value for the nine cities was only 2.5 percent. Thus a conventional modal-split study in Iowa involves the use of such low numbers of bus passengers that the results are of dubious statistical reliability. Furthermore, comprehensive origin-destination surveys have not been made for several smaller cities so that not all the data necessary for a conventional modal-split model are available. For these reasons, this study was designed to produce a model that estimated transit patronage directly rather than as a percentage of total personal travel.

DEVELOPMENT OF MODEL

A mathematical expression or model to estimate transit patronage was derived by regression analysis. Linear, semilog, and log-log forms employing from two to six independent variables were tested for accuracy in reproducing historical data. To simplify calculations and to facilitate comparisons between cities, the average annual number of revenue transit rides per person resident in the area served by a transit operation was used as the dependent variable.

Data Utilized

All available data for 13 transit operations in Iowa for the period 1950 through 1965 were obtained for this study. Because of the limited data for years prior to 1955, only the data for the years 1955 through 1965 were utilized. By using a total of 114 different annual operating periods (an average of 8.8 years for each city), the analysis reflects changes in transit riding habits with time as well as differences among cities.

The transit operations included in this study are located in the cities listed in Table 1. Also given are populations of these cities according to the latest decennial or special

TABLE 1

CITIES INCLUDED IN STUDY

Central City of Transit Operation	Population, Latest Census	Latest Census Year
Des Moines	206,739	1966
Cedar Rapids	103,545	1965
Sioux City	89,159	1960
Dubuque	62,853	1966
Council Bluffs	52,957	1966
Iowa City	41,602	1965
Ames	34,826	1965
Ottumwa	33,871	1960
Clinton	33,331	1965
Burlington	33,285	1965
Fort Dodge	31,707	1967
Marshalltown	22,521	1960
Muscatine	22,194	1966

census. Service areas of seven transit operations also include one or more incorporated places in addition to the central cities given in Table 1.

Variables

Multiple regression models were developed using the data for 114 annual periods for 13 transit operations. A number of different independent variables were used; two described the transit operation itself and the remainder described demographic characteristics of the transit service areas. Some of these variables are given in Table 2 along with their correlations in linear equations with annual rides per capita. Definitions of the variables included in the model developed are given in the following paragraphs.

A revenue passenger is any patron making a single trip for which a fare has been paid for travel on a vehicle operating as part of a regularly scheduled intracity transit operation. However, a single trip may involve transfer between vehicles. Other services, such as chartered trips or buses operated under contract exclusively to transport children to and from school, are not included.

The quantity of vehicle travel involved in providing the service utilized by revenue passengers is recorded in revenue miles. This variable reflects both the quality and the quantity of service, because quantity most commonly is increased either by providing more frequent service so that waiting times are reduced, or by providing service on additional or extended routes so that walking distances are reduced.

The average fare is calculated by dividing the total annual passenger revenue by the number of revenue passengers carried. Thus, this includes the effects of school fares, added charges for transfers, zone fares, and other variations in charges for individual rides.

The nonworker-worker ratio for a city is defined as the number of persons who are not members of the working force divided by the number in the working force. Persons not in the working force include housewives, children, the aged, and the disabled. These groups tend to depend more upon public transportation than members of the working force and are a substantial proportion of total ridership of transit in Iowa. They are the so-called captive riders who lack an alternative to transit for personel travel and, with other captive riders, make up a majority of regular transit patrons in most cities. Thus, the nonworker-worker ratio is useful in the model for indicating differences among cities in the propensity for people to use transit.

TABLE 2

CORRELATION OF VARIOUS VARIABLES WITH ANNUAL RIDES PER CAPITA IN LINEAR EQUATIONS

Variable	Correlation
Revenue miles of service per resident of the service area	0.96
Nonworker-worker ratio, corrected for population of central city	0.52
Population of central city	0.52
Persons per registered automobile in county of central city	0.47
Median family income in central city corrected for population	-0.44
Average fare, corrected for population of central city	-0.39
Population density in central city, persons per square mile	0.30

Equations

The equation that best reproduces historical data for transit patronage and in which all regression coefficients are significant at the 0.01 level is

$$R_c = -33.97 + 1.46W + 0.033C + 3.00S \quad (1)$$

where

R_c = revenue transit rides annually per resident of a transit service area;

W = working force factor = N (log P);

C = city size and cost factor = $\frac{(\log P)^3}{F}$;

S = service factor = $\frac{M}{P_S}$;

N = nonworker-worker ratio for the central city of a transit service area;
P = population of the central city of a transit service area;
F = average fare, dollars;
M = revenue miles of transit service provided in one year; and
P_S = population of all incorporated places in a transit service area.

Or, where R = total revenue rides annually = $R_c P_s$,

$$R = 3.00M + P_s (-33.97 + 1.46W + 0.033C) \tag{2}$$

Further, if Y = total annual passenger revenue in dollars = RF,

$$Y = 3.00MF + 0.033P_s (\log P)^3 - P_s F (33.97 - 1.46W) \tag{3}$$

Eq. 1 has a coefficient of multiple correlation, r, of 0.984 and a standard error of estimate of 2.69 rides per capita per year. A comparison of actual and calculated values of R for 114 annual periods is shown in Figure 1.

Single-Variate Relationships

It may be noted from Table 2 that the correlation between the service factor and transit patronage is extremely high. This relationship is shown in Figure 2. The coefficient of correlation is 0.96 for the expression $R_C = -1.30 + 1.89S + 0.081S^2$.

Although it is apparent from Table 2 that factors such as family income, population density, and automobile registration are correlated with transit usage, they are less significant indicators than the factors used in Eq. 1. For example, the regression coefficient for automobile registration was not significant in any of the expressions derived, and in most such expressions had a sign opposite to its positive correlation. This is caused by the strong correlation of this variable with most independent variables used. Indeed, many of the variables given in Table 2 are interdependent and not actually independent when used together. However, as shown in Figure 3, automobile registration and transit patronage are related. Data for two cities, Iowa City and Ames, have not been included in the figure. Populations of both of these cities include a large proportion, about 40 percent, of university students. Thus, their characteristics are atypical in many respects, including the relationship between population and automobile registration. Figures on registration are available only on a countywide basis in Iowa, but in all counties with transit operations included in this study, the majority of the county population is resident in the transit service area. The expression

$$R_c = -8.05 + 2.19A^3 - 0.0055A^6$$

has a coefficient of correlation of 0.75.

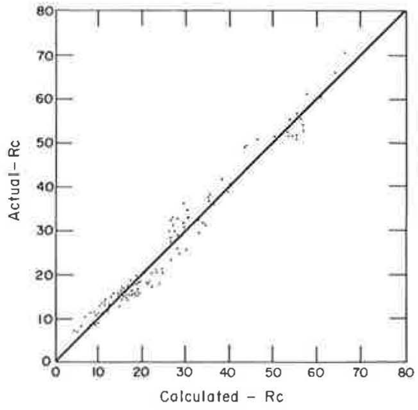

Figure 1. Relationship between actual and calculated values for annual transit patronage per capita.

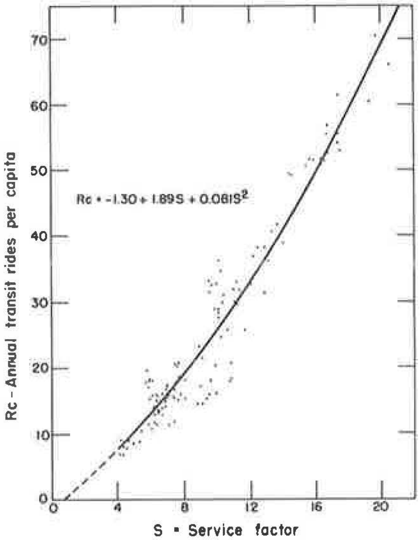

Figure 2. Relationship between level of service and annual transit rides per capita.

Applicability of Model

It must be emphasized that this model has been derived from a study of available data covering transit operations only in Iowa cities. Since these cities have fairly uniform economic and physical characteristics, the applicability of the model should be limited to cities possessing those characteristics. For example, it is probably not applicable to very large metropolitan areas, or other small urban areas outside of Iowa where economic factors, population densities, automobile ownership rates, and other demographic characteristics substantially differ from those typical of Iowa cities.

The model was derived for use as a forecasting tool with general applicability for cities in Iowa. Obviously, other factors will influence a modal choice in a particular city. Parking availability is an example of a factor that might significantly influence the choice between private automobiles and transit for personal travel. The construction of freeways that substantially reduce peak-hour congestion diverts some travel from transit to private automobile. Various other factors will uniquely influence transportation in a given urban area and also ought to be considered. Generally, however, the independent variables utilized adequately describe the propensity of residents of an urban area in Iowa to choose travel by public transit.

DISCUSSION OF MODEL

Significant characteristics of the 1965 transit operations included in this study are summarized in Table 3. For comparison, national averages for bus service in 1965 also are shown where these are available (1). As may be noted, there is considerable variation in these characteristics even though cities in Iowa are quite similar in many respects.

Effect of Change in Service Factor

An analysis of Eq. 3 permits speculation concerning solutions to the problems of marginal patronage and revenues. For example, the equation indicates that additional service will increase revenues at the ratio of three average fares per revenue mile of service, when other variables remain unchanged. If the operating cost per mile for transit service is less than three times the average fare, as is common in the cities included in this study, then increased service should be a profitable undertaking. It may be assumed that additional service would take the form of more frequent service on existing routes of proven passenger potential, special services for which a need exists, or extensions of service into new areas of indicated demand. Actual instances of service increases during the period covered by this study generally confirm this expectation. However, the increased patronage often is very slow to be realized, with a year or more apparently required in some instances before travel habits are adjusted to improved or increased transit service. This factor, of course, often will nullify the profit potential of increased service.

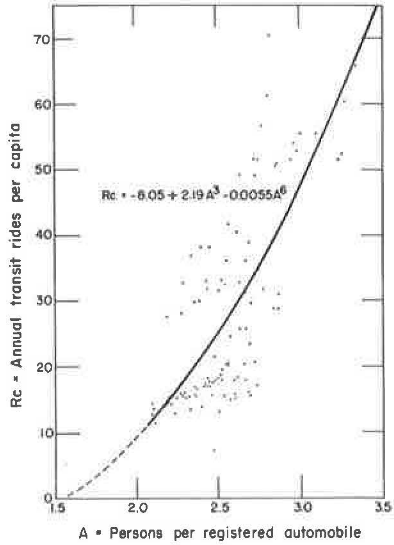

Figure 3. Relationship between automobile registration and annual transit rides per capita, 11 cities.

TABLE 3
SOME CHARACTERISTICS OF TRANSIT SERVICES IN 13 CITIES IN IOWA, 1965

Characteristic	Mean	Median	Range	National Average
Transit usage annually per service area resident, revenue rides	19.95	15.16	6.84-51.58	N. A.[a]
Revenue miles annually per service area resident	8.62	8.04	4.20-15.98	N. A.[a]
Revenue passengers per revenue mile	2.17	1.91	1.63-3.23	3.09
Average fare, dollars	0.193	0.192	0.126-0.253	0.205
Passenger revenue per revenue mile, dollars	0.41	0.39	0.29-0.68	0.64

[a]Not available.

Price Elasticity

The elasticity of revenue with respect to the average fare is somewhat more complex. Increases in fares lead to decreased patronage (Eq. 2), but the proportional decrease depends largely upon the level of service. At high levels of service, S, equal to about 15 annual revenue miles per service area resident, elasticity is about - 0. 3 to - 0. 4 depending on city size (an increase of 1 percent in average fare results in a decrease of 0. 3 to 0. 4 percent in patronage). This is consistent with the rule-of-thumb elasticity of - 0. 33 cited by Fitch (4). When S is about 7. 8 (varying among cities in accordance with the expression $S' = 11.30 - 0.49W$), the elasticity is - 1. 0. At this level of service, increased or decreased fares theoretically will cause no change in passenger revenues. At lower levels of service, transit in Iowa exhibits considerable price elasticity. Under these conditions of service, an increase in fares may lead to an actual decrease in revenue. Fare reductions, on the other hand, should induce sufficient increases in patronage to raise passenger revenues when service levels are low. This conclusion, deduced from Eq. 3, has not been verified by actual experience. It obviously runs counter to the solution of raising fares, usually adopted to increase the profitability of a marginal transit operation in which service has been reduced to low levels. Experience shows that many transit patrons in Iowa have a choice of transportation mode, and many travel by other means when faced with fare increases by an operation providing low levels of service. Only when transit is accompanied by shorter waiting times and reduced walking distances implied by high levels of service does it appear to be relatively price inelastic.

Demographic Characteristics as Indicators of Transit Usage

A model was developed earlier in this study that included several variables that measure demographic characteristics of the communities served by transit (3). However, the model presented here uses several fewer variables, is simpler in form, and reproduces historical data with comparable accuracy. As pointed out earlier, many socioeconomic indicators significantly indicate transit patronage. However, these indicators are closely correlated with characteristics of service and fare structure, which are better indicators. A brief discussion of transit-riding characteristics in Dubuque illustrates the apparent influence of some of the factors that are indicative of modal choice. Since 1957, the trend of transit usage has actually been rising in this service area, which includes East Dubuque, Illinois. In recent years patronage was at a substantially higher level on a per capita basis than in any other urban area included in this study. Patronage averaged 51. 6 revenue transit trips per person during 1965. The level of service during that year was the highest and the average fare the lowest for transit operations studied. At the same time, Dubuque is one of the few cities in Iowa with more than 4, 000 residents per square mile, its nonworker-worker ratio is the highest in the state when adjusted for city size, and Dubuque County has a much higher number of persons per registered automobile than any other urban county in Iowa. Clearly, these demographic characteristics of a community are indicators of the level of transit patronage parallel to the service and fare characteristics of that community's transit operation.

CONCLUSIONS

The model developed from this study permits reasonably accurate forecasts of transit patronage for cities in Iowa. While the model results from analysis of data only for

Iowa cities, the same factors could have limited application as indicators of transit patronage in other cities.

Summary of Results of Analysis

Conclusions from an analysis of the equations derived are summarized as follows:

1. The quantity of transit service, measured in revenue miles, is much the stronger indicator of transit usage. Patronage is related to revenue miles of service in a 3-to-1 ratio under typical conditions. However, increases in ridership resulting from increases in service often are slow to materialize, so that this is not necessarily an easy road to profitability.
2. The elasticity of transit patronage with respect to the average fare varies considerably, depending primarily on the quantity of transit service. At high levels of service, elasticity is about - 0. 3 to - 0. 4, depending on city size. However, patronage is considerably more price elastic at low levels of service.
3. The proportion of the population outside of the labor force is an indicator of the level of transit patronage. The nonworker-worker ratio measures this variable.
4. Other factors being equal, per capita patronage of a transit operation centered in a large city is higher than that of an operation in a small city.
5. The level of transit patronage in an urban area may be strongly influenced by the quantity of service provided and by the fare structure, within limits that depend upon demographic characteristics of the area.

Need for Further Research

Further research is needed to clarify the relationship of transit patronage with the quantity of service and the fare structure in small urban areas. Conclusions deduced from the model developed in this study have not all been verified by some other studies. For example, several demonstration projects in Massachusetts developed comparatively little additonal patronage with either increased service or reductions in fare (5). However, in some instances local service increases were profitable, showing that, if carefully selected, such improvements can be self-sustaining. This conclusion is further supported by experience reported from Memphis, which demonstrated that extensions of service into areas not previously served can prove profitable under certain conditions (6). Other studies reported in the literature, some with contradictory conclusions as to the price elasticity of transit patronage, concern large metropolitan areas with high levels of service and results that probably cannot be related directly to Iowa's much smaller urban areas.

Information more pertinent to this study is afforded by recent experience in Iowa City. This transit operation introduced a uniform ten-cent fare late in 1966. During the last quarter of 1967, patronage was more than double that during the comparable period in 1965 when the average fare was $0. 193. Passenger revenues were about 25 percent higher over this period in 1967 than in 1965. Increases in revenues did not occur, however, until the reduced fare had been in effect for a year, a further indication of the substantial time lag during which travel habits are adjusted to reflect changes in transit service.

Obviously, a better understanding of these relationships is essential if the marginal profitability of the typical transit operation is to be improved. Or, if profitability is not possible or desirable, further knowledge is necessary to establish the amount of public support that, with a given level of service and fare structure, will best help attain the transportation objectives of urban area residents.

REFERENCES

1. Transit Fact Book, 1966 Edition. American Transit Association, Washington, D. C.
2. Automobile Facts and Figures, 1967 Edition. Automobile Manufacturers Association, Detroit, Michigan.
3. Carstens, R. L. Model for Forecasting Usage of Public Transportation in Iowa Cities. Unpublished PhD thesis, Iowa State Univ., Ames, 1966.

5. Mass Transportation in Massachusetts: Final Report on a Mass Transportation Demonstration Project. Commonwealth of Massachusetts, Mass Transportation Commission, Boston, 1964.
6. Mass Transportation Studies in Memphis. Memphis Transit Authority, Memphis, Tenn., 1965.