PROCEEDINGS —

Fifteenth Annual Meeting

Theme:
"Transportation in Focus"

October 10-11-12, 1974
Fairmont Hotel
San Francisco, California

Volume XV • Number 1 1974

TRF

TRANSPORTATION RESEARCH FORUM

FLAT, or nearly flat, fare schemes are common in small- to medium-sized urban bus systems. Since such fares do not vary with trip length, the fare collected per mile fluctuates widely from one trip to another. Questions arise as to the appropriateness of a flat fare structure, both from the standpoint of equity and in relation to system revenue needs. Several factors are pertinent to the analysis of the problem, including operating costs, route length, trip length and demand schedules. This paper will examine the matter largely on a conceptual basis, but also in light of some empirical data which are at least suggestive of prevailing practices and needs.[1]

Over eighty-five percent of the nation's urban bus systems serve cities of under 250,000 in population. It is with the needs of these small- to medium-sized operations that this paper is concerned. Accordingly, the data examined in the study are from systems in this size category. The following section outlines the content, collection method and system environments for the data. Service specification provides a convenient framework within which to begin the investigation, so a brief presentation of the theory's basic concepts is offered as a prelude to the analysis.

Data

The data used in the study were gathered in on-bus surveys administered on two small- to medium-sized systems in western Pennsylvania. Each system employs an essentially flat fare structure in that the charge does not increase with trip length, although variations in the fare level are present in such forms as passes for the elderly and quantity discounts on tokens. One of the systems does collect a five cent surcharge for transfers and for long trips out of (or into) the city. These exceptions to the flat fare policy apply to only a very small portion of the trips. Table 1 summarizes the sizes of the two systems in terms of equipment, ridership and service offerings.

PROFILES OF SURVEYED BUS SYSTEMS

	City A	City B
Population served	135,000	220,000
Number of vehicles	36	55
Route miles	41	105
Daily ridership	5,000	15,000
Annual vehicle miles	645,000	1,555,000

TABLE 1

Questionnaires were administered by surveyors riding on the buses. Each survey encompassed all trips taken on a system for an entire day (excluding non-respondents). The portion of the collected data which is subjected to analysis in this paper consists of the trip length and the fare paid for each trip. Table 2 lists the details of each route

ROUTE DATA

City	Route	Route Length (Miles)		Number of Buses	Headway (Minutes)
A	1	3.87		1	30
A	2	4.04		1	30
A	3	10.56		1	30
A	4	11.38		1	30
A	5	11.95		1	30
A	6	4.74		1	60
A	7	8.09		1	60
A	8	12.89		1	60
A	9	13.05		1	60
A	10	13.86		1	60
B	1	66.10		5	26
B	2	13.60	(morning)	3	24
			(midday)	2	35
			(afternoon)	4	20
B	3	11.60	(morning)	1	39
			(afternoon)	1	30
B	4	9.60		1	39
B	5	21.30	(midday)	1	60
			(afternoon)	1	30

TABLE 2

Some Implications of a Flat Bus Fare Structure

by Hoyt G. Wilson and G. John Kurgan**

surveyed. For routes that operated all day, the data are grouped into three time periods: morning peak, midday and afternoon peak. In the statistical analysis, the data for the two systems are pooled and each route-time period combination is treated as a separate observation.

With one exception, all of the routes fall in a range of about four to twenty-one miles in length. The exception, at sixty-six miles, is far outside these limits. Route length here is defined as the distance required to traverse an entire "loop" and return to the starting point. Hence, for a linear route which proceeds out and then returns along the same path, it would be equal to twice the length of the path.

Where costs enter the analysis, the categories included are variable transportation costs. These consist of fuel, driver wages and vehicle maintenance. A single per-mile figure is calculated for each system based on accounting data. The same per-mile cost is then applied to each route within a system.

Service Specification

The concept of service specification modeling as developed by Rea [1,2] includes an algorithmic procedure for generating feasible transit networks. The use of the concept in this paper, however, will be limited to its method of specifying transit supply functions.

The supply function, or "service specification," consists of a definition of what level of service will be offered at each level of demand (ridership). Rea refers to demand in terms of link flows in a network, but for present purposes this concept can be transformed into ridership for a route. The simplifying assumption is made that for any given headway on a particular route the quality of service (in terms of average speed) is roughly constant over a reasonable range of ridership. A service specification for a route, then, will look similar to the graph in Figure 1. Here, each step on the curve corresponds to decreasing the headway.

**The Pennsylvania Transportation Institute, Pennsylvania State University, Research Bldg. B, University Park, Pa.*

***Transportation Engineer/Planner, Michael Baker, Jr., Inc., Beaver, Pennsylvania.*

One criterion for deciding what demand level justifies a step up to the next level of service is the revenue requirement. That is, as soon as the fare box revenue is great enough to cover the cost of the additional bus hours, the service is increased. This determination, of course, depends upon the fare level and upon operating costs.[2] The points so calculated are called viability points. These points, again, represent the lowest level of demand that can support each level of service. By connecting all of the viability points in Figure 1, one could form a viability boundary.

At the other extreme, the level of service may not be increased until the existing equipment is used to capacity. In this case, the ridership cannot increase until the level of service is increased. Points calculated in this way are called capacity points and connecting them forms a capacity boundary. The capacity and viability boundaries together form the "service specification envelope" for a given set of technologies and levels of service. For the purpose here, going from one level to the next corresponds merely to changing bus headways, but in general it may also represent a change in technology or mode.

ANALYSIS

In the case of a flat fare system, in which the per-mile fare is not constant, the service specification curve as shown in Figure 1 is different for each route length. Assuming that operating cost per bus mile is constant, three variables influence the viability points: route length, passenger flow and headway. Revenue does not increase when average trip length increases, so a longer route requires greater ridership to support it. Instead of taking route length as the implicit given factor, it is interesting to take headway as given and investigate the change in required route passenger flow with changes in route length. This is, in effect, asking, "Given the prevailing policies for changing headways as route length is increased, what are the implied requirements in terms of ridership for routes of different lengths?" In order to answer this question empirically, required flow was regressed on route length. A good fit was obtained ($R^2 = .94$), indicating a fair amount of consistency in the policy for adjusting

GRAPH OF A SERVICE SPECIFICATION FUNCTION

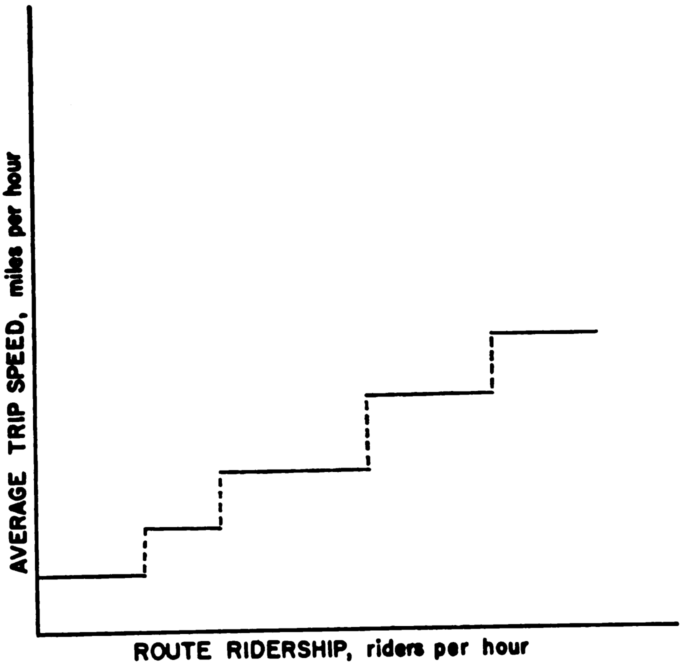

FIGURE 1

headway to route length. The regression line is labeled "viability" in Figure 2.

The next question of interest is how actual ridership compares with that required for economic viability. To investigate this matter, actual route ridership was regressed on route length. The regression line, which achieved an R^2 of .71, is shown in Figure 2 as the line labeled "actual." Comparison of the two lines in Figure 2 reveals that ridership does not increase with route length at a rapid enough rate to support the longer routes, given the flat fare structure and the existing policy for setting headways. Based on the curves in the figure, one would expect a route length of about 3.4 miles to be the demarcation between viable and non-viable routes.

The "actual" line in Figure 2 exhibits a pretty good fit to all of the data, but it was found that when the data for the one very long route were excluded, there was very little correlation between route length and ridership. This could indicate that within a range of moderate changes in route length, ridership does not vary systematically; it is only when a drastically longer route is offered that a significant ridership increase is observed. If this result is accepted, for a moderate range of route lengths (say, three to twenty miles), the actual ridership in Figure 2 would become horizontal at a height equal to the average ridership for those routes. In this case the intersection with the viability curve would occur at a route length of about 6.4 miles, a substantial difference from the 3.4 miles obtained previously. The available data simply are not adequate to pinpoint the intersection of the curves more accurately. The essence of the conclusion is the same in either case however: a flat fare system does not appear to be able to support longer routes; the longer the route, the larger is the deficit to be expected.

The change in actual ridership with route length (Figure 2) is affected by several underlying relationships, two of which are

(1) the relation of trip length to route length and

(2) the relation of ridership to trip length.

In order to investigate the first of these, average trip length (for a route) was regressed on route length. A straight line fit the data very well ($R^2 = .97$), with a slope of 0.55. This result is interesting as it suggests that as route-miles are added, the new portions are utilized at the same rate as the old portions. That is, route segments appear to be rather homogeneous in terms of passenger flows. In particu-

RIDERSHIP AS A FUNCTION OF ROUTE LENGTH

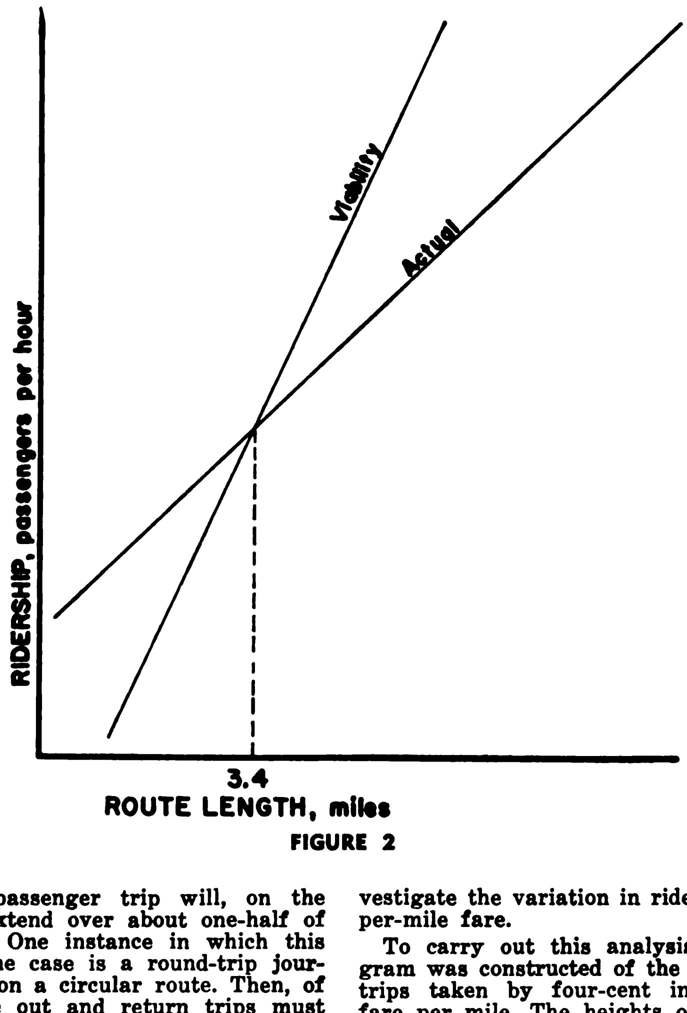

FIGURE 2

lar, any passenger trip will, on the average, extend over about one-half of the route. One instance in which this must be the case is a round-trip journey made on a circular route. Then, of course, the out and return trips must sum to the total route length. Such journeys undoubtedly contribute heavily to the result obtained, however a good share of the trips in the data do not fall into this category.

The next relationship of interest is that between ridership and trip length. Since the fare is invariant with trip length, the price of transportation in terms of dollars per mile is an inverse function of trip length. The fares in the sample data are flat in that they are invariant with distance, however the fares do vary between systems and among classes of riders (e.g., a reduced fare for senior citizens). This suggests that a meaningful way to look at the variation in ridership with trip length is to include the price variable and investigate the variation in ridership with per-mile fare.

To carry out this analysis, a histogram was constructed of the number of trips taken by four-cent intervals of fare per mile. The heights of the bars appeared to decrease in the manner of an exponential decay function of the form

$$Y = Ae^{-BX}$$

where Y is the number of trips and X is the per-mile fare. This equation was fitted by regressing the logarithm of number of trips on per-mile fare (the mid-point of each bar on the histogram). The fit was very good, yielding an R^2 of .96. By normalizing the function—that is, adjusting the constant so that the integral from zero to infinity is unity—a density function is obtained which gives the portion of the trips which fall in any range of per-mile fares. This calculation yields

$$P(X) = 8.92\ e^{-8.92\ X}.$$

Then the fraction of all trips that fall in the range between A dollars per mile and B dollars per mile is given by

$$\int_A^B P(X)\, dX.$$

Note that the function P(X) is an exponential probability density function with mean $(8.92)^{-1} = 0.112$.

In addition to trips, the number of passenger miles at each per-mile fare level is of interest. Carrying out the same calculations on the distribution of passenger miles yields a density function.

$$Q(X) = 12.98\ e^{-12.98\ X}.$$

The value of R^2 for the regression is again .96. Both functions are graphed in Figure 3. As should be expected, the distribution of passenger miles is more concentrated, since a trip at a lower per-mile fare represents more passenger miles than a trip at a higher per-mile fare when the total fare is constant.

These distribution functions, particularly that for passenger miles, provide a cross-sectional picture of how demand varies with price. They offer the transit operator an estimate of how much of his "product" is being purchased at each price. It should be made clear, however, that they do not constitute demand schedules as the term is used in economics. In particular, they do not reveal how the quantity of service purchased would vary with changes in the fare level. Nevertheless, they do confirm that users do indeed purchase more transit trips at lower prices and fewer at higher prices.

Summary and Implications

The foregoing analyses must be interpreted in the context of the objectives of a typical transit operation. Most transit authorities do not hope to earn a profit, but rather are more concerned with the service they provide. It may be questioned, then, whether an analysis of route profitability, such as that in Figure 2, is pertinent to their needs. The answer is that if revenue requirements are at all constraining—that is, unless unlimited subsidies are available—then such considerations are very pertinent to the determination of what service can be offered. For example, if one route is operated at a large loss, that severely limits the service that can be offered on other routes. If such a money-losing route is only lightly pa-

DENSITY FUNCTIONS FOR TRIPS AND PASSENGER MILES

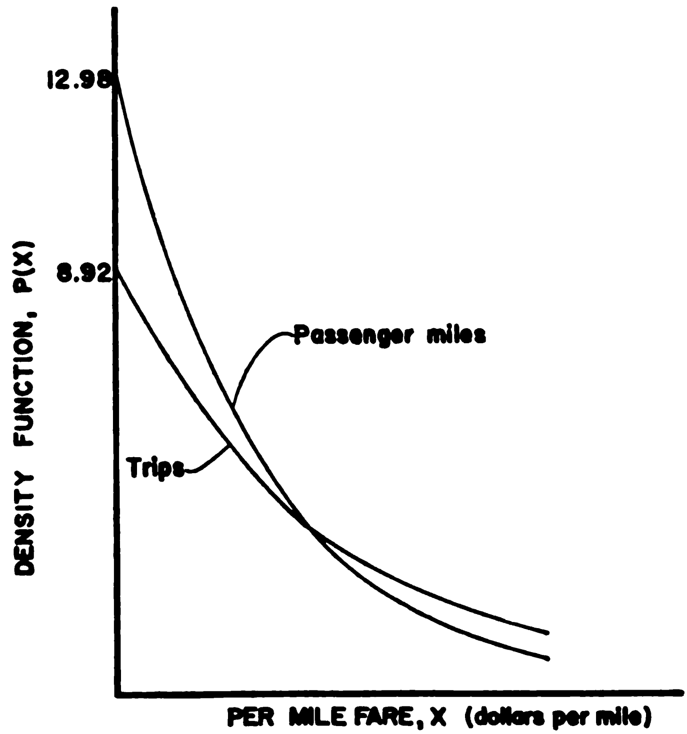

FIGURE 3

tronized, it might be possible to increase the net benefits to transit users by spending the money to provide service elsewhere. In a similar vein, those trips taken at a high per-mile fare are in a sense subsidizing the lower-priced trips. From the standpoints of both equity and revenue considerations, it is reasonable to strive for a narrower distribution of per-mile fares.

It was shown earlier that both trip length and ridership appear to increase linearly with route length. This suggests that there is no essential change in the pattern of demand for passenger miles as route length increases. The same conclusion is supported by the distribution of passenger miles as shown in Figure 3. The smooth analytical curve (exponential density function) exhibits an excellent fit to the data even though the data represent several different route lengths and fares. The thrust of these observations is that it evidently would not be inappropriate to charge on a per-mile basis at a uniform rate, independent of the length of the trip. In other words, a passenger mile is a passenger mile.

Blind adherence to a constant per-mile fare might well be modified for three economic reasons. First, administrative cost sets limits on the precision of such a pricing scheme. The relative costs of defining zones, printing tickets and inconveniencing the driver dictate how coarse the practical approximation should be. Simplicity and ease of collection are the primary incentives for using a flat fare system. Second, the cost of a bus mile on a longer route, on which the average trip is longer, is undoubtedly somewhat lower than for a shorter route. This would justify a somewhat tapered rate as trip length increases. Third, and in a similar vein, there are some constant costs associated with picking up and discharging a passenger. These include wear and tear on the equipment due to stopping and starting and delay costs to other passengers. Such considerations argue for a small minimum fare in addition to the per-mile charges.

Besides the economic reasons just mentioned, a transit authority may wish to deviate from a constant per-mile fare policy on the basis of non-economic considerations. Transit can be utilized as a means of subsidizing residents or industries in certain localities. It can also be a tool for influencing the patterns of land development and geographic population distribution. Buses may be heavily subsidized in order to reduce traffic congestion on certain routes. Such manipulations may be entirely valid, although they are well outside of the intended realm of this study. Attention here is focused on economic matters.

In summary, observations verify that there is a wide variation in the price paid per mile under a flat fare system. Given observed transit usage behavior and the existing policies for setting headways, a flat fare scheme cannot support longer routes; the longer the route, the greater is the deficit to be expected. Both equity and revenue considerations call for a fare structure that increases with trip length. The distribution of patronage by per-mile fare indicates that the quantity of service demanded varies systematically with price, irrespective of trip length, route length or headway. Based solely on demand considerations, then, a constant per-mile fare seems to be appropriate, although cost factors call for some modification of this policy.

It is emphasized that no hard and fast conclusions can be drawn from the small sample of data employed here. The results should be regarded as indicative of existing patterns and conditions. Whether the findings apply to larger systems or even to other systems of comparable size can only be determined by further studies.

REFERENCES

1. Rea, John C., "Designing Urban Transit Systems: An Approach to the Route-Technology Problem," *Highway Record No. 417* (1972).

2. Rea, John C. and Miller, James H., "A Comparative Study of Transit Technologies: The Service Specification Envelope Approach," Research Report PA-11-0010-4, (TTSC 7209), Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, August 1972.

FOOTNOTES

1 Data used in this study were gathered as part of a project supported by the UMTA University Research and Training program at the Pennsylvania State University.

2 Just what constitutes operating costs for this purpose is open to some question.