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Allocation of Bus Transit Service

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To achieve an equitable distribution of its transit service, the Southern California Rapid Transit District intends to allocate service by formula to the communities it serves. The formula would have measures of ridership and population. Before a decision maker can set the relative weights of these two variables, the effect on service levels in the various constituencies must be determined. This paper describes a study that determined the formula that came closest to prescribing the existing levels of service. Data on population, service levels, and ridership were obtained from a system of area accounts, in which data are maintained at the census-tract level and then aggregated into larger areas as required. Regression was used to determine that the formula that best fit existing service levels would have weights of 48 percent on ridership and 52 percent on population. It was found that a better fit was obtained when service was measured in dollars expended rather than in bus kilometers.

In any public enterprise, efficient operation is no more important than is the fair distribution of services. The inherent conflict between these two objectives can be dealt with in a transit service policy in which productivity is maximized within the constraints specified by a distribution policy. Total amounts of service for each subregion of a service area can be set and, given these amounts, the service within the subregions can be adjusted to be as productive as possible.

The question of distribution has previously been cast by Levine (1,2) as a problem in the allocation of transit operating deficits. Such an approach stems from the need to apportion deficits among tax-contributing political jurisdictions served by a single operator. In the case of Los Angeles, in which deficits are covered by tax funds collected on a geographic base broader than the area served (i.e., state and federal taxes), it is more appropriate to allocate the entire cost of service. Within that allocation, both deficits and user charges can be considered.

The Southern California Rapid Transit District (SCRTD) has been exploring the approach of formula allocation of service, which would function much like the formula used to distribute federal transit operating funds to urbanized areas. As with the federal formula, residential population would be one variable. The other variable, rather than population density, would be a measure of ridership.

A requisite for such an allocation formula is having a suitable data base. A system of area accounts was developed at SCRTD for this purpose. Maintained at the census-tract level, these accounts include transit service and use data in addition to the demographic data normally available by census tract. All transit data are attributed to bus stops and from there to the census tract in which the stop is located.

SCRTD obtains ridership data by bus stop for a number of purposes--scheduling, route planning, reporting as required by Section 15 of the Urban Mass Transportation Act of 1964, and area accounts. The cost of obtaining and processing the data is less than 1 percent of the operating budget, and the increment attributed to maintenance of the area accounts is a small fraction of that.

The question of distribution is inherently a political one and must be decided in a suitable manner. Before decision makers can or will make a decision on a formula, they must know how their constituencies will be affected. The subject of this paper is a study undertaken to determine the existing distribution of service in relation to a potential formula. By using multiple linear regression of the data provided by the area accounts, the level of service is estimated from explanatory variables such as ridership and population.

The SCRTD distributes its services over a broad and diverse geographic area. Although there has been no formal policy on allocation, the distribution is not random. The analysis reported here was undertaken in order to test an underlying (if unconscious) rationale. Questions of primary interest are

1. How closely is service level correlated with the combined factors of population and ridership within the local areas?
2. If we assume such a relationship, what is the relative emphasis on each of the two factors in the current distribution of service?
3. If a formula were adopted and adhered to, what would the effect be on service levels in the various geographic areas?

Some secondary questions were also addressed:

1. What happens if service level is defined by bus kilometers instead of by expenditure level?
2. Once variations in service level due to population and ridership are accounted for, what is the effect of a third variable that indicates transit dependency?

ALLOCATION FORMULAS

Allocation is the splitting of a resource among the members of a group. Any allocation formula can be reduced to the form

$$y_i = \sum_j a_j x_{ij} \qquad (1)$$

where

$$\sum_i y_i = \sum_j a_j = \sum_i x_{ij} = 1$$

where

- y_i = fractional share of the resource that will go to the ith recipient,
- x_{ij} = fractional share of the jth variable associated with the ith recipient, and
- a_j = proportion of the total resource to be divided up according to the shares of the jth variable.

In the allocation of transit service, the resource is the total amount of transit service as measured by vehicle kilometers or cost. The recipients are the local service areas, which are the subdivisions of the total service area.

CHOICE OF VARIABLES

There has been no attempt to carry out a broad search for the best (in the statistical sense) explanatory variables for existing service allocation. Rather, it was deemed more germane to explore the effects of the few politically reasonable variables. Of major interest were ridership and population. Ridership is taken to mean boardings per day, although other definitions could have been used. Allocating service according to the amount of riding that actually occurs seems to be a way of paying attention to the efficiency of the service. On the other hand, the fairness of distribution of service to the community is served by allocation according to the population of each area. This recognizes the public's contribution through taxes.

A suggestion has been made that contributed tax monies could be used directly as a variable rather than population. When the areas used for units of distribution are not actually tax-collecting units, the tax contribution of each area must somehow be estimated. When broad sources of revenue are considered, a question is raised about the attempt to return service to residents in direct proportion to actual tax monies contributed. That would be in direct conflict with the view that transit is in part a welfare institution intended especially to bolster the mobility of the poor in compensation for their disproportionate lack of access to the automobile-dominated transportation system. A simple population count would treat people as equals without regard to wealth.

Although service level could be reckoned in several ways, the two measures explored were bus kilometers per day and dollars of operating cost per day. The latter might not seem to be a good measure of what the consumer receives or is offered, yet it can still be valid as an indicator of the resource expended on his or her behalf. There is no reason to think that resources are arbitrarily or uncontrollably wasted in some areas; hence the measure could be viewed as a reasonable indicator for comparisons among areas. In the congested areas in which costs are higher due to slow movement of the buses, it can be argued that the congestion causes the value of a kilometer of travel to be higher.

Cost is computed as a linear combination of kilometers and hours of bus travel while the bus is actually in service:

Cost = bus hours x \$30 + bus kilometers x \$0.31.

It might be better if other variables were included that would better allocate the higher costs of service during peak periods, but it is more difficult to aggregate such data on an area basis. To the extent that the degree of peaking is similar from one area to another, this shortcoming should have little effect on the resulting allocation.

CHOICE OF UNIT AREA FOR DATA AGGREGATION

There are several objectives in choosing the basic unit of area for the analysis. There should be

1. A large-enough number of areas for statistical reliability,
2. Areas large enough to smooth out local land-use variations (e.g., local parks, industrial areas, and arterial street locations), and
3. Areas that are internally homogeneous yet externally heterogeneous with respect to the variables of interest.

Although the data are compiled by census tract, these are not suitable for direct use and must be aggregated into larger areas. Besides being so small that random irregularities unduly influence the data, census tracts are purposely delineated to encompass populations of similar size. Being externally homogeneous with respect to population, they are inherently poor as units for regressions in which population itself is a variable that is being considered.

In a typical regression, one obtains as many data points or cases as practical to increase the statistical reliability of the relationship that is being determined. In analyzing a distribution within an area, the number of data points can be increased simply by dividing the total area into smaller parts. In this analysis, a division into 13 areas was of direct interest, since those areas (the SCRTD planning sectors) were naturally favored as the basic units for adjustment of service level. As a test of the effect of subarea size, a second set of 86 county zones was used. These areas had previously been defined by the county road department for the analysis of transit services and were aggregations of census tracts.

REGRESSION TRIALS

Even though the scope of the search for a good formula was narrowed considerably by the initial choice of variables that were politically viable, several problems in the data had to be explored, such as the inclusion or exclusion of service data from municipal operations, use of area totals or densities, and alternative indicators of service level.

The data used were from the 1970 census and from line checks taken during 1977 and 1978. Although these may not be true cross-sectional data (as they should be), the service levels were relatively stable during that two-year period, as was patronage. The population of the county was stable between 1970 and 1978. Data from park-and-ride services were not included, but one would not expect this omission to cause much error, since such service is less than 2 percent of the district's total and it is not concentrated in any one area.

The regressions were carried out by Anne Huck by using the Statistical Package for the Social Sciences. Table 1 gives the conditions of the 12 regression trials that were run. Table 2 gives the numerical results, the formula coefficients, and the coefficient of multiple correlation.

Missing Data for Municipal Operators

Within the service area of the SCRTD, there are several territories served primarily by municipal operators. Although they are mostly quite small (they provide less than 15 percent of the total service among them), they are major providers in a few relatively small areas. To the extent that municipal operations share in the use of public funds, the service they offer and the ridership they carry should be considered in analyzing the distribution of transit service. Since actual data on those operations do not exist in a suitable form for area accounts, some rough estimates were made.

The estimates were practical only in the cases with a few large zones. In the small-zone cases, in which municipal service could not be readily esti-

Table 1. Parameters of regression trials.

Parameter	Trial Number 1	2	3	4	5	6	7	8	9	10	11	12
Number of data points	78	86	86	77	77	12	12	12	12	14	12	13
Express service included			X	X	X	X	X	X	X	X	X	X
Variables expressed as												
Totals									X	X	X	X
Densities	X	X	X	X	X	X	X	X				
Service expressed as												
Cost (dollars)	X	X	X	X				X	X	X	X	X
Kilometers					X	X	X					
Municipal areas												
Included		X	X			X	X	X	X	X	X	X
Omitted	X			X	X							
Municipal service												
Estimated						X	X	X	X	X	X	X
Omitted	X	X	X	X	X							
No-car variable included							X					
Central business district included										X		X

Table 2. Computed coefficients.

Trial Number	Coefficient a_0	a_1	a_2	a_3	R
1	0.13	0.24	0.62	-	0.9920
2	0.14	0.25	0.61	-	0.9910
3	0.16	0.23	0.61	-	0.9834
4	0.17	0.22	0.62	-	0.9841
5	0.22	0.28	0.50	-	0.9565
6	-0.02	0.47	0.54	-	0.9620
7	-0.13	0.80	0.84	-0.51	0.9678
8	0.15	0.21	0.64	-	0.9800
9	0.05	0.50	0.45	-	0.9927
10	0.02	0.51	0.47	-	0.9911
11	0	0.54	0.46	-	0.9971
12	0	0.52	0.48	-	0.9967

Note: a_0 = constant; a_1 = coefficient of population; a_2 = coefficient of ridership (boardings); a_3 = coefficient of no-automobile households; and R = coefficient of multiple correlation.

mated, the regressions were run with and without the data points that represent the zones in question. Using these zones without accounting for municipal service has the same effect as if some areas were to have especially low SCRTD service and ridership relative to the population size of the zone. Omission of these zones from the analysis involves the assumption that service levels in areas dominated by municipal operations are consistent with levels in the SCRTD service areas. The effect of leaving out those zones was slight. Only one percentage point was transferred from the population coefficient to the ridership coefficient in the two-factor apportionment formula.

Variables Expressed as Densities or Totals

Although the formula variables for which the coefficients are to be determined are expressed in terms of totals for any specified area, the coefficient of multiple correlation (R) will be artificially high. Use of totals is associated with a scale effect in which a comparison of a larger area with a smaller one will tend to show a larger amount of service, ridership, population, etc. This induces a falsely high correlation of the variables. By using densities (riders per square kilometer, population per square kilometer, etc.), the effect can be neutralized.

Nevertheless, since we are looking for the best fit in terms of totals, that is the way that the final result should be presented.

Effect of Zone Size

The effect of the zone size can be inferred from a comparison of trials 4 and 8. The weighting of the ridership coefficient differs by only two percentage points; hence it might be concluded that the size of zone has no great effect on the determination of coefficients.

Express-Service Considerations

Express service is characterized by long distances between stops and long passenger trips. Therefore, the unit area size most suitable for allocation purposes will be larger than that for local service. Bus kilometers in express service are attributed to stops that precede express-operation segments of lines and may generally be considered to be balanced between directions. Boardings in express services are attributed to stops at which they actually occur, which are usually on a local segment of the line.

The consequence of this data arrangement is that a few census tracts will seem to be receiving an excess of service simply because they contain a stop that defines one end of an express segment of a line. The best way to deal with the situation would be to segregate express services and deal with them separately in a manner that recognizes the greater travel distances and dispersed benefits. However, since there really is not a great amount of express service, and since the end points are reasonably evenly distributed throughout the area, there is little effect on the regression coefficients by inclusion or omission of express kilometers. This can be seen by comparing the coefficients in trials 2 and 3; express kilometers of service were omitted in trial 2 and included in trial 3.

Choice of Variable to Describe Service Level

If regression trials 4 and 5 are compared, the choice of the variable to describe service level can be seen to have a marked effect. When service was measured in dollars (trial 4), the service level appears to be heavily weighted toward ridership (ridership coefficient, 0.62). When measured in bus kilometers (trial 5), the ridership coefficient is only 0.50.

The result can be explained as follows. Although ridership density is highly correlated with population density, it tends to fall off rapidly as population density declines, so that ridership is usually low in areas of moderate population density. Thus in areas of moderate density, in which population is the governing factor in determining service level, higher operating speeds are also prevalent. Higher speeds mean more kilometers per dollar of service cost. Thus, service measured in kilometers tends to correlate better with population, whereas service to be equivalent to one that specifies service in dollars tends to correlate relatively better with ridership. This means that for a formula that specifies kilometers of service to be equivalent to one that specifies service in dollars, it will have to have a relatively lower coefficient for ridership.

The correlation coefficient (R) is significantly better for dollars than it is for kilometers. In other words, not only is the relationship different, but it is more consistent in one case than it is in the other.

Constant Term

The normal result of a linear regression is a coefficient for each variable plus a constant term. Although a nonzero constant is to be expected from an investigation of a de facto allocation policy, it is not something to be included in an intentional formula. If that were done, the formula would allocate service to any defined area even if it had no riders or population.

To force a zero constant (trials 11 and 12), each data point was simply matched with another data point in the negative quadrant. However, this gives a false enhancement of the correlation coefficient.

Addition of a Transit-Dependency Variable

It is often said that transit service is allocated mostly on the basis of need and that need is expressed through demonstrated ridership. There is some circularity in this argument, in that ridership is to an extent a response to service offered. What if two areas are compared that have the same population and ridership yet differ in some other innate indicator of need?

It is not easy to say what single variable best represents transit dependency, but being without access to an automobile in the household seems to be a reasonable definition for an initial analysis. For data, a count of no-automobile households in each area was used, which was obtained from the 1970 census. This variable was appended to the other two for a three-variable regression.

The result was a negative coefficient for the transit-dependency variable. This means that, if two areas are equal in population and ridership, we could expect to find less service in the one with the highest transit dependency. Although this is in keeping with the normal market strategy in private business (i.e., to be the most competitive in areas in which people are most likely to have a ready substitute), it might not be what we think of as appropriate strategy for a public enterprise.

Best-Fit Formula

The coefficients for the formula that best fits the existing allocation of service are taken from trial 12:

$$S_i = 0.48R_i + 0.52P_i \quad (2)$$

where

S_i = share of service dollars expended in the ith area,
R_i = share of boardings, and
P_i = share of residential population of that area.

The service levels prescribed by this formula differ from the actual levels by less than 20 percent in all 13 of the service sectors; the average deviation is 11 percent.

CONCLUSIONS AND IMPLICATIONS

Although service levels vary over a wide range throughout the service area studied, they follow a rather consistent pattern, which can be described by two variables--ridership and population. The existing patterns were not consciously laid down in those terms, but the politically and operationally determined need for service seems to imply at least a subconscious connection with these or similar factors.

Even though service levels seem reasonably consistent in following an apparent rationale, there was no easy way for decision makers to explain how service resources were allocated. The formula approach offers a way to explain the variation in service levels to the public. Those levels now in existence can be adjusted over time for greater consistency by means of a formula.

Intentional changes in the formula coefficients can be used as a policy tool to shift the relative emphasis of service between the provision of standby service for the population at large and more capacity in areas in which ridership actually exists.

The analysis addressed the issue of how services are currently distributed and the consequences of a range of trade-offs between the two formula variables chosen. Is there any basis for deciding what the relative weights should be?

More-productive service, in terms of the least cost per rider, will be the result of a formula heavily weighted toward ridership. Obviously, moving too far in that direction would be politically impossible because of the tax-support issue. But the actual amount of tax funds should allow a lower bound to be placed on the ridership coefficient in the formula. Through the fare box, the riders pay for 46 percent of SCRTD service, so it seems reasonable that at least 46 percent of the service should be apportioned according to ridership. To the extent that some of the tax support is used directly to subsidize certain fare payers (the elderly, the handicapped, and students), the minimum-ridership factor should be adjusted upward to about 51 percent. Thus the range for political decision seems to be a population coefficient between zero and 49 percent. Even at the higher end of this range, this would entail a slight reduction from the present split of 48:52 (ridership:population).

Until experience with a two-variable formula has been acquired, the complexity of additional variables may not be appropriate. The result of adding a variable that represents transit dependency seemed interesting enough to include in this discussion, however. Further research in this area might be worthwhile.

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