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Stratification Approach to Evaluation of Urban Transit Performance

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In a period of growing transit operating deficits, increasing attention and concern is being directed at both the decreasing levels of productivity of transit systems in general and the broad differences in measured service performance compiled for various transit systems. In making these performance assessments, analyses have commonly relied on highly aggregated industrywide data and have not given adequate consideration to the changing and unique operational context within which individual transit systems must function. This paper presents a stratification approach to the evaluation of urban bus transit system performance. The stratification scheme was used on the premise that there exist many environmental and policy factors outside the control of the transit operator that constrain the performance of the transit system. Factors such as area population, population density, union work rules, system configuration, fleet age, and operational forms have strong influences on the productivity and efficiency levels of an individual transit service. By implementing the stratification procedure and compiling temporal data pertaining to both environmental and policy influences and system performance, the possible bias in making assessments and comparisons of existing transit systems can be controlled, and changes in performance levels of a system in response to both external changes and operational improvements can be predicted.

Performance measures based on available operating, financial, and ridership statistics have recently been considered as criteria for the evaluation of public transit systems. Such measures can provide much insight into the operation of a particular system. In addition, these measures can be used to examine the differences among various transit systems and the changes that may occur from year to year. However, the injudicious application of generic performance indicators in the direct comparison of systems can provide misleading information about the relative effectiveness of the systems' operation and service. To compare systems adequately, it is necessary to adopt an approach that can allow for the unique local environments over which the operator has limited influence.

Implicit in past research activities on transit performance has been the necessity of addressing the issue of comparability of productivity elements and procedures by which comparable elements can be defined and generated (1-3). Yet little research has been done on the examination of performance measures on a stratified basis. In general, the existing research focuses on the performance evaluation in terms of such broad categories as the type of operation (e.g., fixed route versus demand responsive) and organization (municipal service versus transit district) in order to facilitate the comparability of system performance for use in managerial analyses (1). The purpose of this paper is to extend the issue of comparative evaluation of the systems and to examine the external factors that cause the variations in performance from one system to another.

Table 1. Stratification factors, variables, and data sources.

Stratification Factor	Variable	Data Source
Congestion	Average vehicle operating speed	Systemwide measure derived from 1975 American Public Transit Association (APTA) operating report; will also be available from Financial and Reporting Elements (FARE) system; calculated by dividing bus miles by bus hours
Wage rate	Average wage per driver	Systemwide measure; derived from APTA data and calculated by dividing compensation to operators by operator person hours; wage will be available from FARE
Population	Number of people in urban area in which system operates	Obtained from 1975 APTA data; in FARE system this is reported by metropolitan planning organization (MPO)
Population density	Population per square mile of land area in urbanized area, central city, and service area	MPO will provide these data to satisfy FARE requirements and will obtain necessary data from system route maps and available census population data
Organization type	Qualitative distinction (e.g., municipal transit authority, contract management)	Obtained directly from transit management; not provided by FARE; highly susceptible to error due to varying definitions of management types
Network configuration	Qualitative distinction (e.g., radial, grid, circumferential)	Determination made from route maps of transit systems; also susceptible to error due to definitional inconsistencies
Local transit policy	Percentage of trips by elderly, percentage of work trips, percentage of elderly population	Elderly population available from census reports; distribution of trips by rider characteristics (age, sex, income, handicap) and by trip purpose (work, shop) will be provided by MPOs from transit-user surveys; available from FARE
	System age	Years transit system publicly operated; information available from transit systems

STRATIFICATION FOR EVALUATION OF PERFORMANCE

If all bus systems operated in identical environments and under similar policy constraints, their performance in different locations could then be explained only in terms of variations in level of service. Presumably, under such conditions, performance differences would then be a function of operator-controlled variables; thus the operator would have the potential to improve the system's performance by increasing the level of service provided.

However, environmental and policy factors external to the local transit operating decisions are not all alike, and it is the major thesis of this research that some of the ways in which they differ affect the inherent productivity of the bus systems. Population density, congestion, and network configuration are most often cited as intruding environmental and policy effects (1,3). These and other elements outside the transit operator's control can have a significant effect on certain performance indicators that are used to describe system productivity. Their impact becomes apparent when vehicle mileage, for example, is used in a productivity measure. Since vehicle mileage is affected by each of the above factors, there is little doubt that a vehicle mile traveled in Milwaukee is not the same as a vehicle mile traveled in New York City. The absence of congestion, for instance, may raise the vehicle's average speed; the result is that more vehicle miles are driven by a particular driver. The failure to consider such an effect will result in misleading productivity measures. Consequently, several environmental and policy factors that appear to constrain performance of transit systems are given below and discussed in the following sections.

Factors	Type of Influence
Population	Environmental
Population density	Environmental
Congestion	Environmental
Wage rate	Policy
Local transit policy	Environmental and policy
Organization type	Policy
Network configuration	Environmental and policy
System age	Policy

STRATIFICATION FACTORS

The following discussion presents several factors that affect bus transit performance either directly or indirectly. As such, these factors are potentially useful in establishing a stratification scheme that can be used to explain the variation in the productivity observed among bus operations. In the discussion of each factor, a basis for its use and possible variables used to quantify each factor are presented. Table 1 gives a list of stratification factors and the variables by which the factors are measured. Also included are their respective data sources. For the purpose of this discussion of an application of the stratification approach, only three factors were chosen, those for which data are now available on a consistent basis so that the factors can be measured.

Congestion

Transit productivity is closely related to travel speed. As speed increases, a given driver can operate over more route miles in a given period. To a certain extent, vehicle operating speed can be controlled by the operator. For example, by increasing or decreasing the number of stops along a route, operating speeds will decrease and increase, respectively. However, vehicle operating speeds are mainly determined by street-system characteristics and local traffic policies and perhaps affected only marginally by transit operating policy. In general, a bus transit management operates its vehicles as fast as traffic conditions permit in order to maximize vehicle use. Thus it is felt that the average vehicle operating speed actually achieved by an urban transit system reflects to a large extent the degree of congestion present in the urban area.

Since operating statistics are reported only on a systemwide basis, the measure of speed is necessarily rough. Nevertheless, incorporation of systemwide average vehicle speed as a stratification variable is defensible on the ground that if some of the detail is obscured, this is so for all systems in the sample.

Wage Rate

A major component of the operating cost is wages paid to drivers and support staff. In general, labor costs are responsible for 50-60 percent of the total operating expenditure. However, since labor costs differ by geographical area, this factor is important for system stratification. The variable used in this analysis is the average wage per vehicle operator of a transit system.

Population

If an indicator of productivity such as passengers per revenue vehicle mile, for example, is used as a measure of transit performance, consideration must then be given to the population characteristics of the community the system serves. If levels of service are equal, passenger use has been found to vary directly with population. Accordingly, total population of the urban area is the variable used in the system stratification scheme.

Other Factors

As shown in the list above, there are several other factors that can be considered in the stratification procedure. Such factors include population density, organization type, and network configuration. Local transit policy is also a critical factor. Although these factors could not be included in the present analysis because of the absence of relevant data on a consistent basis, a brief discussion of their general significance and possible effects is presented in the following paragraphs.

Population Density

There is little disagreement that the population as well as the area of a city play some role in both the provision and the consumption of transit service. Although size of the population alone can give some indication of ridership levels, additional insight into transit performance can be gained if land area is integrated into the analysis. In general, transit service is more efficiently and effectively provided in high-density areas (1). Furthermore, transit operational and financial performance is affected not only by density of residential population, but also by the density and size of nonresidential (i.e., industrial and commercial) clusters in an urban area (4). The significance of such a relationship permits estimation of the effect of different land-use policies on transit performance.

Organization Type

Identification of organizational structure and management can also contribute to the differences in transit performance, since they vary with type of service, the area served, and the preferences of local government. In a study by Bakr and others (5), the ability of various types of organizations to undertake tasks commonly associated with the management of a transit system was examined. It was observed that government-managed transit systems appeared to perform less effectively due to the lack of necessary support personnel needed for operation and management responsibilities. On the other hand, transit authorities, by their nature, were found much more efficient and effective in providing service, since they are much more flexible and innovative in implementation of management and operational policy. The researchers also concluded that contract management performs a justifiable role in the current state of development in the public transportation sector. It can help improve overall performance, since contract management can provide standardized procedures, planning, and scheduling techniques. Managerial performance can be improved, since expertise is accumulated from years of experience, which includes extensive experience in labor negotiations.

Network Configuration

A bus system's performance can be affected by the way in which certain geographical, topographical, and governmental policy constraints force it to develop its network. Network configuration reflects the nature of a city's land-use and street-network patterns. Thus the consideration of bus system network layout can offer insight into aspects of quality and accessibility of transit performance. For example, rectangular networks generally do not follow desire lines as closely as do radial networks, and consequently more transfers may be required, which affects the quality of the system.

Local Transit Policy

In addition to the factors described above, local transit policy is a critical determinant of the performance of transit systems. Since public transportation may exist for different reasons in different cities, it is only reasonable to consider various policy issues to see what goals and objectives the system is expected to achieve. For example, it seems that most performance measures do not reflect the extent to which systems serve special groups such as the elderly and the handicapped. Failure to recognize urban areas that have large concentrations of such special population groups may result in inaccurate assessments of transit performance. In general, it would seem reasonable to assume that those transit systems that provide a high level of service to the elderly and the handicapped would incur higher unit operating costs than do those systems in cities with a small elderly and handicapped population.

Similar distinctions can be made by disaggregating transit operations with respect to peak-period and base-period service. In general, a system largely oriented toward commuters would appear to be much more efficient and effective during peak hours than during the off-peak period. This situation is common for systems that provide late-night (owl) service.

The number of years the system has been publicly owned can also reflect differences in operating and financial performance. It might be reasonable to suggest that those systems that have recently made the change from private to public ownership reflect poor service and passenger use together with low quality of service, which might be indicated by limited accessibility to the service. Initially, such systems are likely to be characterized by absence of the strong public and political support needed for successful development of good management and high ridership.

Although lack of reliable and uniform data does not allow stratification of systems on such bases as organizational type and network configuration, information on rider characteristics provided by user surveys required by the Financial and Reporting Elements (FARE) system of the Urban Mass Transportation Administration can make possible examination of performance on the basis of certain policy varibles such as the percentage of the elderly and the handicapped served.

STRATIFICATION APPROACH

Stratification can be accomplished in many ways. Techniques range from those schemes that stratify by one criterion--for example, whether a system is large or small--to a level of disaggregation that generates a unique description for each transit system. The method developed in the current study

Figure 1. Schematic representation of stratification scheme.

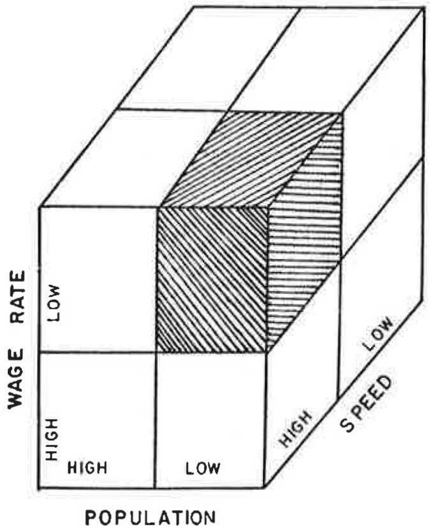

Table 2. Initial stratification of wage, speed, and population variables.

Level	Average Wage ($/h)	Average Speed (mph)	Population (000 000s)
Low	<4.75	<12.5	<250
Medium	4.75-6.00		250-750
High	>6.00	≥12.5	>750

seeks to achieve a level of stratification that lies between these two extremes.

The approach taken is basically a classical taxonomic procedure. To begin, all systems are included in one class. Based on the stratification factors selected, for which data are available, systems are stratified to form cells, or groups of stratification-factor levels. The performance of transit systems within each cell can then be explained by the stratification factors and factor levels.

The primary variables for the stratification approach presented here include average driver wage, average vehicle operating speed, and total urban population of the area in which the system operates. These are variables that not only are reflective of the operating environment under which the systems provide service, but also are essentially independent of the systems operator's influence on transit operations. In addition, measures that reflect system performance are needed, since it is the purpose of stratification to explain variation of performance from system to system. In the present analysis, resource use indicators were considered, such as vehicle miles per vehicle, vehicle miles per driver, and revenue passengers per driver. These measures reflect vehicle use, labor productivity, and labor use, respectively.

In general, each variable can be considered separately, in relation to another, or both to determine appropriate stratification groups. For instance, in considering total population, the stratification can be initiated by disaggregating the corresponding variable into two or three intervals. This stratification then results in a small number of cells; each cell contains many systems. Alternatively, it is possible to stratify in such a manner that each system defines its own unique cell. The objective in determining which stratification scheme is most appropriate involves a trade-off between maximizing the extent to which the variability in system performance can be explained through stratification and maintaining a manageable and practical stratification scheme.

Figure 1 illustrates a simplified schematic stratification scheme. For example, the shaded portion of Figure 1 indicates those bus systems that can be characterized as having an operational service environment with low population, high speed (low congestion), and low wage rate. Development of a final stratification scheme involves the incremental modification of the initial stratification shown in Figure 1. For example, the scheme may involve changing both the number of factors used and the factor levels (or one of these) until an adequate stratification is achieved.

In order to assess the adequacy of a proposed scheme, one must examine the stratification scheme with respect to the performance measures; i.e., does the particular stratification scheme adequately explain the variability in the performance measures? In other words, once cells have been obtained, a check is made to see whether the measures (computed as the mean of each cell) vary with each cell. To make this determination, univariate analysis is used to study the behavior of the mean values for the performance measures within each cell of the stratification scheme. This particular statistical procedure is effective in establishing whether (a) performance variation can be explained by environmental and policy factors or (b) performance variation cannot be explained by using such factors.

STATISTICAL METHOD

The analysis of variance (ANOVA) was applied in this study for development of the stratification scheme for evaluation of transit system performance. ANOVA is merely a procedure by which the total variation in the dependent variable is subdivided into meaningful components. For this application, the dependent variables are the performance measures. The meaningful components are the stratification (independent) variables that are hypothesized as adequate explanations of the variation in performance for the transit systems sampled.

The statistical criterion that is used to examine the adequacy of the scheme is the R^2-value (coefficient of determination). R^2 is simply interpreted as the proportionate reduction of total variation associated with the independent variables. As the R^2-value increases, it will be stated that the variation of the selected performance measure decreases. The change in the R^2-value then becomes the basis for the introduction, modification, or both of the stratification variables. The level of significance in explaining the total variation of a performance measure by a stratification scheme was set at 5 percent. Furthermore, the Burr-Foster Q-test (2) was used to establish the homogeneity of population variances, which is required by the ANOVA technique.

EXAMPLE OF STRATIFICATION APPROACH

The three stratification (independent) variables used here include average driver wage, average vehicle speed, and total urban area population. These variables were disaggregated into several intervals. For the initial iteration, strata were formed as shown in Table 2. The initial choice of variables and class intervals is a judgmental decision. However, the major requirement statistically for the formation of class intervals

Table 3. Results of stratification by wage, speed, and population variables.

Transit Operation	Stratification Variable: Wage ($/h)	Speed (mph)	Population	Performance Measure: Vehicle Miles per Vehicle	Vehicle Miles per Driver	Revenue Passengers per Driver
Cell 1: Low Wage, Low Speed, Low Population						
Central WV TA, Clarksburg, WV	3.65	11.11	28 864	25 218	23 642	47 743
Broome County Transit, Binghamton, NY	4.21	12.46	167 224	35 262	21 322	39 291
Duke Power Company, Anderson, SC	4.38	11.44	27 556	24 116	14 470	20 011
Duke Power Company, Greensboro, NC	3.23	11.77	73 638	29 257	21 672	36 632
Montgomery Area Transit, AL	3.99	11.24	138 983	27 724	21 887	38 850
Mean				25 489	20 599	36 506
Cell 2: Low Wage, Low Speed, Medium Population						
Metropolitan Transit Authority, Des Moines, IA	4.37	9.44	255 824	20 785	19 900	–
Cell 3: Low Wage, High Speed, Low Population						
Corpus Christi Transit System, TX	3.08	13.42	212 820	56 933	31 882	37 257
City Utilities, Springfield, MO	4.19	12.81	121 340	18 216	21 528	22 211
Greenfield and Montague Transportation Area, MA	3.38	12.69	18 116	18 722	18 722	27 149
Bay County Metro TA, Bay City, MI	4.53	13.52	78 097	41 160	14 316	9 564
Monterey Peninsula Transit, CA	4.06	12.96	93 284	38 071	22 208	16 819
Hudson Bus Lines, Lewiston, ME	3.05	16.40	65 212	11 187	12 065	9 170
Mean				29 953	20 120	20 362
Cell 4: Low Wage, High Speed, Medium Population						
Metropolitan Tulsa Transit Authority, OK	3.86	12.70	371 499	34 333	25 328	30 010
Metropolitan Transit Authority, Wichita, KS	3.53	12.99	302 334	37 687	27 961	32 064
Sun Tran-City, Tucson, AZ	4.50	13.01	297 451	40 953	25 173	33 671
Austin Transit Corporation, TX	4.57	13.61	264 499	46 607	21 909	30 425
Central Pinellas Transit Authority, St. Petersburg, FL	3.42	13.86	495 159	47 121	27 487	26 954
City Transit Division, Southeastern Pennsylvania TA	4.32	15.10	685 942	41 721	16 688	16 954
Mean				39 924	24 091	28 346
Cell 5: Low Wage, High Speed, High Population						
North Suburban Mass Transit District, Des Plaines, IL	4.69	14.59	6 714 578	14 409	14 409	17 187
Dallas Transit System, TX	4.68	13.62	1 338 684	31 584	24 076	44 625
Mean				22 997	19 242	30 906
Cell 6: Medium Wage, High Speed, Low Population						
Kanawha Valley Regional Transit Authority, Charleston, WV	6.00	13.62	157 662	34 709	28 635	47 983
Lane County Mass Transit, Eugene, OR	5.25	14.49	139 255	48 067	22 531	22 375
South Carolina Electric, Charleston, SC	4.96	12.53	228 399	41 684	24 222	60 514
South Carolina Electric, Columbia, SC	4.89	12.76	241 781	38 982	24 892	53 728
Ft. Wayne Public Transportation Corporation, IN	5.73	13.45	225 184	29 882	24 902	29 898
Madison Metro, WI	5.00	14.02	205 457	22 030	25 041	74 885
Mean				35 634	25 037	48 230
Cell 7: Medium Wage, Low Speed, Medium Population						
CNY Centro, Syracuse, NY	4.95	11.55	376 169	25 831	18 806	47 823
Calgary Transit, Alberta, Canada	5.58	11.90	403 319	29 518	–	–
Capital District TA, Albany, NY	4.80	11.78	486 525	26 975	20 036	43 203
Metro Regional Transit Authority, Akron, OH	4.77	11.96	542 775	29 890	14 945	24 221
Sandwich Windsor, Windsor, Ontario, Canada	5.12	10.17	258 643	28 507	20 332	57 935
Mean				27 113	18 530	43 295
Cell 8: Medium Wage, Low Speed, High Population						
New Orleans Public Service, Inc., LA	4.72	10.27	961 728	23 792	15 023	59 092
Metropolitan Dade County TA, FL	5.66	10.24	1 219 661	–	21 127	65 794
Rhode Island Public Transit Authority	4.95	10.72	795 311	35 392	20 444	53 005
Mean				29 592	18 864	59 297
Cell 9: Medium Wage, High Speed, Medium Population						
City and County of Honolulu DOT Services, HI	5.45	14.44	442 397	44 490	21 902	66 154
Cell 10: Medium Wage, High Speed, High Population						
City of Detroit DOT, MI	4.93	14.63	3 970 584	36 032	26 052	–
Metropolitan Atlanta Rapid Transit Authority, GA	5.71	13.91	1 172 778	37 742	25 315	54 255
Metropolitan Transit Commission, St. Paul, MN	5.82	12.91	1 704 423	25 846	21 899	44 089
Metropolitan Transit Authority, Houston, TX	5.61	13.43	1 677 863	40 132	23 304	40 024
Southwest Ohio Regional Transit Authority, Cincinnati, OH	5.87	12.68	1 110 514	28 008	22 353	52 912
Tri-County Metropolitan Transportation District, Portland, OR	5.84	14.57	824 926	39 335	23 953	31 616
Mean				33 040	23 812	44 579
Cell 11: High Wage, High Speed, Medium Population						
Tacoma Transit System, WA	7.54	12.60	332 521	27 473	21 105	43 229
Toledo Area Regional Transit Authority, OH	6.30	13.48	487 789	29 190	25 675	62 186
Mean				28 331	23 390	52 707

Table 3. Continued.

Transit Operation	Stratification Variable			Performance Measure		
	Wage ($/h)	Speed (mph)	Population	Vehicle Miles per Vehicle	Vehicle Miles per Driver	Revenue Passengers per Driver
Cell 12: High Wage, Low Speed, High Population						
Bi-State Development Agency, Alton, IL	7.10	12.50	2 987 850	26 081	19 971	35 032
City of Long Beach, NY	6.43	12.15	8 351 266	39 933	24 323	48 596
Milwaukee Transport Services, Inc., WI	7.28	11.76	1 252 457	34 608	19 748	50 412
Niagara Frontier TA, Albany, NY	6.23	10.79	1 086 594	–	17 158	51 600
Regional Transportation District, Denver, CO	6.41	11.80	1 047 311	29 000	16 162	25 252
Chicago Transit Authority, IL	7.70	8.84	6 714 578	36 204	16 383	–
Montreal Urban Community Transit Commission	7.27	9.87	2 743 208	24 232	15 888	63 900
Toronto Transit Commission	7.02	12.15	2 628 043	37 921	–	–
Mean				29 858	18 519	45 799
Cell 13: High Wage, Low Speed, Medium Population						
Ottawa-Carleton Regional Transit Commission, Ontario, Canada	6.66	11.88	602 510	34 070	21 030	57 055
Winnipeg Transit System, Manitoba, Canada	6.25	10.96	540 262	30 516	17 147	71 752
TA of River City, Louisville, KY	7.41	12.33	739 396	22 141	15 599	34 914
Mean				28 093	17 925	54 574
Cell 14: High Wage, High Speed, High Population						
Alameda-Contra Costa TD, Oakland, CA	8.56	14.42	2 987 850	30 003	18 527	33 960
Indianapolis Public Transportation Corporation, IN	6.43	12.86	820 259	22 809	18 200	34 378
San Diego Transit Corporation, CA	7.28	14.47	1 198 323	36 145	23 758	58 135
Southern California Rapid Transit District, Los Angeles, CA	6.28	13.22	8 351 266	30 775	18 576	45 354
Central Ohio Transit Authority, Columbus, OH	6.06	12.58	790 019	27 435	20 558	37 858
Southern Michigan TA, Detroit, MI	9.21	16.60	3 970 584	27 614	26 009	27 660
Transport of New Jersey, Trenton, NJ	7.11	14.24	7 168 164	37 451	26 423	41 812
Mean				30 289	21 722	38 980
Cell 15: Medium Wage, Low Speed, Low Population						
Cumberland-Dauphin-Harrisburg TA, PA	5.22	11.41	240 751	17 315	20 595	33 561
Savannah Transit Authority, GA	5.73	11.88	163 753	33 922	22 869	44 974
Tri-State Transit Authority, Huntington, WV	4.96	12.06	167 583	24 491	25 190	36 463
Berks Area Reading TA, PA	5.49	10.00	167 932	27 397	20 091	37 882
Luzerne County TA, Kingston, PA	5.95	12.13	222 830	–	22 045	43 056
Mean				25 781	22 158	39 187

Note: TA = Transportation Authority; DOT = Department of Transportation; TD = Transportation District.

Table 4. R^2 and significance values for stratification evaluation.

Stratification Variable	Performance Measure	R^2	Significance
Average driver wage	Vehicle miles per vehicle	0.489	0.013[a]
Average vehicle speed	Vehicle miles per driver	0.500	0.012[a]
Total urban area population	Revenue passengers per driver	0.570	0.001[a]

[a]Significant at the 0.05 level.

is that variances among cells formed must be homogeneous.

The stratification cells formed are shown in Table 3. By using the ANOVA technique, it was found that the variability in each of the performance measures can be adequately explained by the proposed stratification scheme. Table 4 gives the values for R^2, the criterion used to evaluate the scheme. It can be noted that this stratification scheme, which uses average driver wage, average vehicle speed, and total urban area population as independent variables, explains 49 percent of the variation in vehicle use, 50 percent in labor productivity, and 57 percent in labor use. On the basis of these results, it can be concluded that the stratification scheme appears to be statistically acceptable. The variation that remains unexplained can be due to a variety of factors, among which are differences in level of service and inaccuracies in data.

Implications of these results can now be examined in terms of the selected performance measures. For illustrative purposes, the issue of system comparability is discussed in the following paragraphs.

The types of results shown in Table 3 can be used to make a specific evaluation of the performance of a particular system. As an example, consider those systems that make up cell 14. Here the performance of an individual system (that of Indianapolis, for example) can be compared with the mean performance of all the systems in that cell. While this is being done, however, several questions may arise regarding the remaining variation in performance among systems in that cell. This can be the result of policy or operational conditions.

If we look first at the vehicle-use measure (vehicle miles per vehicle), Indianapolis has a value (22 809) that falls below the mean (30 289). Although the high average operating speed of the Indianapolis system suggests that the ratio should be higher (since more vehicle miles would be generated at higher speeds), this is not always the case. In fact, a lower-than-average value may indicate that the system is providing a higher level of service by using a large fleet for the number of vehicle miles operated. On the other hand, service may be characterized by low frequency; this results in fewer miles traveled by each vehicle. Consequently, for low values of this measure, both effective and ineffective use of vehicles can be the case, depending on the particular characteristics of the system.

Likewise, labor productivity, indicated by vehicle miles per driver, can also be interpreted in different ways. For instance, due to certain policy constraints, run cuts and schedule problems may not permit efficient allocation of operating personnel between peak and off-peak periods. A low value (18 200) for Indianapolis Public Transportation Corporation relative to the mean (21 722) may suggest such a problem. On the other hand, the high value for Transport of New Jersey (26 423) suggests that this type of policy constraint has less influence in this system. However, it also suggests that other policy constraints require a system that uses all drivers to service areas.

Finally, revenue passengers per driver, a labor-use indicator, shows a wide range--from 27 660 for Southern Michigan Transportation Authority to 51 835 for San Diego Transit Corporation. In this case, low patronage may be the result of improper or inadequate route coverage; this may indicate that the system covers a service area with low transit demand. Low patronage may also be the result of certain service-related policy constraints. For example, if a system is mandated to provide an extensive service for the transportation disadvantaged such as the elderly and the handicapped, it may not show a high value for revenue passengers per driver. Other local transit policies, particularly those associated with fare levels and fare structures, can also affect the patronage significantly.

EFFECT OF STRATIFICATION BY WAGE, SPEED, AND POPULATION ON OTHER PERFORMANCE MEASURES

Since stratification helps to explain the variation in performance among urban transit systems, there may be certain performance measures that can be better explained by the stratification than those shown in the previous section. The statistical results are given in Table 5. It can been seen that, for stratification on the basis of wage, speed, and population, the variation in performance measures such as total operating cost per vehicle, driver cost per vehicle hour, and revenue passengers per vehicle hour (among others) is explained reasonably well by this scheme as indicated by R^2-values of 0.548, 0.807, and 0.673, respectively. There are also certain other performance measures (such as driver cost per total cost and operating ratio) that are not significantly explained by the variables used in this stratification scheme.

Although urban population, wage rate, and average vehicle speed have been identified as the basic set of stratification variables, there are other variables that are potentially useful in establishing a stratification scheme, as was indicated in Table 1. It is not possible at this time to consider all these variables, due to the lack of data. However, similar analyses to this one should be undertaken once the appropriate data become available on a consistent basis so that those factors that would facilitate the understanding of the variation in performance from one system to another can be determined. As a preliminary indication of the effect that one variable has on transit performance, the following section presents the stratification of 51 bus systems by the age of the systems since they have been publicly operated.

Table 5. Effect of stratification by wage, speed, and population on selected performance measures.

Performance Measure	R^2	Significance
Vehicle miles per employee	0.526	0.005[a]
Vehicle hours per bus	0.427	0.055
Percent peak vehicle use	0.516	0.012[b]
Total operating cost per vehicle mile	0.672	0.001[a]
Total operating cost per vehicle	0.548	0.004[a]
Driver cost per vehicle hour	0.807	0.001[a]
Driver cost per total cost	0.328	0.263
Total maintenance cost per passenger	0.469	0.032[b]
Total administrative cost per passenger	0.480	0.062
Total cost per passenger	0.534	0.003[a]
Percentage of population served	0.341	0.290
Percentage of transfers	0.366	0.248
Revenue passengers per vehicle mile	0.647	0.001[a]
Revenue passengers per vehicle hour	0.673	0.001[a]
Revenue passengers per population served	0.581	0.001[a]
Revenue per vehicle	0.483	0.038[b]
Revenue per revenue passenger	0.431	0.053
Operating ratio	0.277	0.502
Deficit per passenger	0.450	0.042[b]

[a]Significant at the 0.01 level. [b]Significant at the 0.05 level.

TRANSIT SYSTEMS STRATIFIED BY SYSTEM AGE

Inherent in this discussion is the fact that, depending on the adequacy of the data and the refinement desired, there are some stratification variables that may be better than others in explaining variation in transit performance. For example, knowledge of the age of a system since it became publicly operated can add insight into transit operational performance, as discussed in the section that describes stratification variables.

Table 6 gives the results of stratification by system age for the 51 bus systems for which data could be obtained. The analysis covered the years up to 1975. It should be noted here that the analysis includes only those systems that operate in the United States. Canadian systems were not considered, since Canada's governmental transit programs differ greatly from those under which U.S. systems operate. The results reported are significant at the 95 percent confidence level. The results show that systems that have become publicly owned after 1969 show significantly lower vehicle use (2085 vehicle-h/vehicle) than do systems that were publicly owned in 1969 or earlier (2462 vehicle-h/vehicle). Similarly, passenger use appears lower for younger systems, as indicated by the low value of 17.2 for revenue passengers per

Table 6. Results of stratification by system age.

	Mean Performance				
Performance Measure	Public After 1969	Public Since 1969 or Earlier	All Systems	R^2	Significance
Number of observations	26	25	51	-	-
Vehicle hours per vehicle	2085	2462	2262	0.107	0.024[a]
Operating expense per vehicle ($)	33 512	42 231	37 508	0.129	0.012[a]
Revenue per passenger ($)	0.38	0.30	0.34	0.104	0.028[a]
Deficit per capita ($)	4.38	9.54	6.68	0.118	0.018[a]
Revenue passengers per capita	17.2	36.2	26.1	0.157	0.025[a]

[a]Significant at the 0.05 level.

capita as compared to 36.2 revenue passengers per capita for older systems.

Consequently, systems that have been publicly owned since 1969 or earlier (six years or longer) appear to be more efficient in terms of vehicle and passenger use. Because of strong and continuing political and public support, such systems have been able both to make certain capital improvements and to implement policies that provide increasing service levels. Purchase of new buses, for example, has allowed transit systems to provide longer hours of service with fewer vehicles, whereas certain policy issues such as fare stabilization have helped to assure continued patronage.

If we consider only the financial efficiencies, however, those systems that have been public since 1969 (less than six years) appear to be more cost efficient. Table 6 shows that operating expense per vehicle, on the average, is lower ($33 512) than it is for older systems ($42 231). Not only can these systems operate at lower unit costs, but they also appear to be more revenue efficient; revenue per passenger is $0.08 more than it is for the older systems (Table 6). In general, the revenue efficiency of younger systems may be explained by a fare policy that reflects the momentum of the profit-making objective of privately operated transit systems.

It should be noted that, for each of the performance measures presented in Table 6, the R^2-values (which reflect the extent of explanation of variation in transit performance) range between 0.104 and 0.157. These values indicate, for example, that only 10.4 percent of the variation in vehicle use (as measured by vehicle hours per vehicle) can be explained by stratifying 51 transit systems according to system age. These results are as expected, and they suggest that other environmental and policy variables might be more useful in explaining variation in urban transit performance when considered together with system age.

CONCLUSIONS

In this paper, a method has been developed by which certain environmental and policy variables have been found useful in explaining the biases inherent in transit performance measurement. Through the example presented, the extent of influence on transit resource use of the elements of wage rate, average operating speed, and population has been identified.

Since such a procedure appears to explain performance variation adequately, its usefulness in comparative evaluation is evident. Such evaluations lend themselves to direct comparison of systems within their respective cells. Bus system performance can be compared against the mean cell values of performance indicators of similar properties. These mean values constitute a par against which comparisons can be made, primarily by managers of a transit property.

Stratification is therefore useful in explaining the possible bias in making assessments and comparisons of bus transit systems. However, it is important to stress that the stratification scheme presented here is only a beginning. Subsequent analyses that use additional environmental and policy factors will undoubtedly improve the reliability and validity of the stratification scheme. The stratification approach to comparing the performance of alternative systems holds promise of being a powerful program-analysis and system-evaluation tool.

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Effects of Small-Scale Transit Improvements on Saving Energy

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The effects of small-scale transit improvements on saving energy in New York State's eight metropolitan planning organization (MPO) areas are examined. Actions included in the transportation system mangement (TSM) plans of the eight MPO areas are analyzed for their effects on ridership, mode shifts, and energy savings, as well as on the energy costs of development, implementation, and operation. Each of 11 transit-related TSM actions is analyzed separately. These transit improvements result in average annual energy savings of more than 25 million equivalent L of gasoline over the period 1978-1980. This is about 0.1 percent of the total annual gasoline consumption in New York State but is 2.6 percent of transit energy consumption in the eight MPO areas. When demand-responsive services, which have high energy costs, are excluded, the average annual saving increases to 3.1 percent of transit energy consump-