Use of Productivity Factors in Estimating LRT Operating Costs

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Estimation of annual operations and maintenance (O&M) costs is an important component of the alternatives analyses for proposed light rail transit (LRT) systems. UMTA's recommended method for estimating O&M costs involves developing productivity-based cost models. In this paper, data are assembled on several key productivity relationships—those most central to LRT O&M cost models—from existing LRT systems over several years, and the implications of these data for estimating O&M costs of proposed systems as part of the alternatives analysis procedure are considered. Operations and maintenance productivity rates are compared among LRT properties, and the year-to-year stability of rates within properties are examined. Two basic data sources are used: the annual UMTA Section 15 data base and the results of research conducted among a group of new and old LRT properties to refine the information provided in Section 15 and other published sources. Analysis of the Section 15 data reveals wide apparent divergences in productivity rates among systems, as well as substantial year-to-year instability in the productivity data of several LRT systems. Several explanations are offered for these patterns, and implications for LRT O&M cost estimation methods are discussed.

It is increasingly common for cities that have for many decades been served only by bus transit to consider introducing light rail transit (LRT) systems. In virtually every jurisdiction in which new LRT systems have been considered, a formal "alternatives analysis," prepared according to detailed UMTA guidelines (*1*), has been conducted. One important component of these alternatives studies is the estimation of the annual operations and maintenance (O&M) costs of proposed LRT systems.

UMTA's recommended method for estimating O&M costs involves the development of productivity-based cost models. Holec and Peskin (*2*) reported on the application of this method to the Houston Transitway Alternatives Analysis in 1981. Since then, the method has been used in numerous alternatives analyses, including recent studies in Baltimore, Maryland; Milwaukee, Wisconsin; Salt Lake City, Utah; and Austin, Texas. The method mathematically relates underlying productivity measures, such as vehicle maintainers per vehicle-mile traveled, to annual measures of transit output and to unit factor prices, so that annual costs for specific operations or maintenance activities are derived on a line item basis. As an illustration of this method, the general form of a resource buildup equation for vehicle maintenance mechanics is as follows: Annual vehicle maintainer cost = annual vehicle-miles × vehicle maintainers per vehicle-mile × average annual hours worked per maintainer × average hourly wage for vehicle maintainers × fringe benefit rate.

To derive such resource buildup models for cities that do not have LRT systems, it is necessary to obtain productivity rates from existing systems in other jurisdictions and apply those rates to the LRT system that is being planned, under the assumption that the productivity relationships of existing systems would apply to the new system. The purpose of the work described in this paper was to assemble data on several key productivity relationships—those most central to LRT O&M cost models—from existing LRT systems over several years and to consider what implications these data have for estimating O&M costs of proposed systems as part of the alternatives analysis procedure.

In this paper, operations and maintenance productivity rates among LRT properties are compared, and the year-to-year stability of rates within properties is examined. Two basic data sources are used: the annual UMTA Section 15 data base and the results of research conducted among a group of new and old LRT properties to refine the information provided in Section 15 and other published sources. Analysis of the Section 15 data reveals wide apparent divergences in productivity rates among systems, as well as substantial year-to-year instability in the productivity data of certain LRT systems. Several explanations are offered for these patterns, and implications for LRT O&M cost estimation methods are discussed.

SYSTEMS SURVEYED AND DATA SOURCES

The LRT systems surveyed include seven older systems (in Boston, Massachusetts; Cleveland, Ohio; New Orleans, Louisiana; Newark, New Jersey; Philadelphia, Pennsylvania; Pittsburgh, Pennsylvania; and San Francisco, California) and four newer systems (in Buffalo, New York; Portland, Oregon; Sacramento, California; and San Diego, California). For several reasons, the UMTA Section 15 data base was used as one of the basic information sources. First, UMTA's technical guidelines for alternatives analysis recommend building up operations and maintenance cost functions according to Section 15 "function codes"—that is, the functional breakdown of costs required under the Section 15 reporting system. As a result, the Section 15 data base is an obvious source of data for cost model development because its data naturally fit the prescribed model format.

Second, Section 15 data allow relatively uniform data def-

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initions over time and among properties, so they appear to be the best data to use for making intrasystem and time series comparisons. Although several studies of Section 15 data have indicated that reporting errors are common in the Section 15 data base (*3*), the detailed reporting instructions sent to transit systems each year and the mandatory audit procedures under the Section 15 program lend a measure of credibility and uniformity to the data base. There is some evidence that Section 15 data have improved over time.

Finally, Section 15 data are readily available and can be obtained at relatively little cost. This factor is important in alternatives analysis procedures because if the data collection schemes used in the O&M cost estimation task are costly and time-consuming, they will drain resources from other important tasks, such as patronage forecasting.

The other basic data source is research performed as part of a staffing plan for a new LRT system that is under development (henceforth referred to as the new LRT study). During this effort, a number of staffing plans were collected from presentations at the 1988 TRB-sponsored LRT conference (May 8–11, 1988, in San Jose, Calif.). Current staffing rosters and operating statistics were also obtained directly from a number of LRT properties. Additional telephone contacts were used to clarify some of the earlier information. Data were collected directly in this way from new LRT systems in Portland, Buffalo, Sacramento, and San Diego, and from the Newark City Subway.

RESEARCH FINDINGS

The key finding of the in-depth research was that there is little similarity in measured productivity rates among properties. In part, the variability among properties can be attributed to differences in equipment, labor practices, environmental conditions, and operating procedures. It also appears, however, that much of the variation in productivity rates among systems may be due to differences in data definitions or errors in data reporting and collecting procedures. One indication of this problem is the extreme year-to-year variability observed within properties. We believe that this variability cannot be explained by actual underlying changes in productivity. Because of these results, it is suggested that extreme caution be used in applying productivity factors derived from Section 15 data to the prediction of operating costs for a new LRT system.

Some possible explanations for the variability within the Section 15 data are presented in the following sections. In these sections, we present some specific examples of the types of labor productivity factors in which practice and statistics vary widely.

PRODUCTIVITY RATE COMPARISONS

Together, the eight O&M cost categories examined in detail in this section typically make up about 75 percent of all LRT operations and maintenance costs. The data presented for the older systems are from 1982–1985, whereas the information for the new systems reflects their recent opening dates. For some systems, an examination of Section 15 data reported between 1979 and 1981 reveals extreme productivity rate values. Because of these extreme values, which were almost certainly the result of initial misunderstandings about data definitions or other problems associated with the break-in period for the program, Section 15 data from years before 1982 are not used.

Vehicle Operator Productivity

The annual revenue train hours per revenue vehicle operator is a measure of operator productivity that lends itself readily to the resource buildup approach to O&M costs. Table 1 provides this information for the systems studied. This table was derived from Section 15 data by adjusting the annual revenue vehicle hours per revenue vehicle operator by the ratio of the average number of trains in peak service to the average number of vehicles in peak service.

Variations in the productivity rate principally reflect differences in labor agreements and crew scheduling practices, such as differences in overtime practices, split shift and guaranteed day provisions, and the "fit" between cycle times and an eight-hour work shift. However, more detailed knowledge of the staffing practices of the various properties produces other explanations. Some properties find it better to retain fewer operators on the roster but pay them overtime, whereas others minimize overtime pay and keep a larger extra board. On occasion, both Cleveland and Newark have trained bus drivers as rail operators but have not put them on a separate rail operators' roster. These operators are used as extra operators when needed but are not counted for Section 15 reporting.

In another example, Boston, Cleveland, and San Francisco operate multicar trains but require an operator on each car to collect fares. This practice should give the appearance of lower productivity by the operator (measured in train hours) when compared with properties that operate multicar trains with only one operator. It should be noted, however, that the San Diego case does not support this hypothesis. One possible explanation is that other factors are at work, such as overtime or ability to use part-time workers. Table 2 gives staffing versus peak vehicles in operation for four new LRT systems, which all use a single operator per train.

Because averages from other systems are not likely to be an accurate reflection of the terms of the labor agreement or current practice on any specific property, another approach to determining operator labor costs was used in the new LRT study. The first step in this approach was to create an initial

TABLE 1 ANNUAL REVENUE TRAIN HOURS PER REVENUE VEHICLE OPERATOR

	Year			
System	1982	1983	1984	1985
Boston	471.7	911.5	–	1057.9
Cleveland	541.4	677.3	566.7	555.5
New Orleans	1552.8	1493.2	1991.6	1826.1
Newark	1707.8	1692.2	1323.0	1987.5
Philadelphia	1262.0	1545.0	1664.5	1294.0
Pittsburgh	1069.7	1312.2	1235.5	1847.6
San Francisco	1166.3	1213.5	1466.3	1264.9
San Diego	938.6	1072.6	1040.3	989.8
Buffalo				1667.7[a]
Portland				1035.7[a]

[a]1987 data.

TABLE 2 STAFFING VERSUS PEAK VEHICLES IN OPERATION

System	Peak Vehicles	Operators
San Diego	25	31 full-time, 18 part-time
Portland	22	34
Buffalo	23	23
Sacramento	23	23

operating plan, complete with headway book, and thereby to determine the number of platform hours required to operate the system. The next step was to determine the number of platform hours per full-time equivalent (FTE) operator per year. Dividing that number into the number of platform hours produced the number of FTE operators the system would require.

The O&M cost portion of the new LRT study used 1,500 platform hours per FTE operator per year, which appeared to be a representative average of a number of properties and was reasonably close to current experience of the property that was expected to operate the new system. On this basis, the new LRT line was predicted to require 33.25 FTE operators. After cutting runs on the basis of the current labor agreement and using the same headway book, the property's schedule department suggested that the line could be operated with only 30 operators. Because the two estimates came to within 10 percent of each other, this approach (using platform hours per FTE operator per year) appears to be reasonable. It permits an existing property to tailor the productivity more closely to the property's experience, if applicable. Even if the existing operation is motor bus only, the measure of platform hours per FTE operator will reflect existing labor practices that are likely to carry over to the new LRT operation.

TABLE 3 REVENUE VEHICLE OPERATORS PER OPERATIONS SUPPORT AND SUPERVISORY PERSONNEL

	Year			
System	1982	1983	1984	1985
Boston	1.86	0.94	-	2.09
Cleveland	3.19	2.58	1.34	3.17
New Orleans	4.84	4.58	8.04	4.00
Newark	5.67	5.67	5.33	2.97
Philadelphia	2.87	7.55	4.42	8.33
Pittsburgh	6.52	3.69	2.07	0.92
San Francisco	7.56	5.53	5.47	5.14
San Diego	2.10	2.30	2.55	2.00
Buffalo				0.90[a]
Portland				2.06[a]
Sacramento				1.10[b]

[a]1987 data.
[b]From Sacramento staffing plan.

TABLE 4 ANNUAL VEHICLE MILES PER REVENUE VEHICLE MAINTAINER

	Year			
System	1982	1983	1984	1985
Boston	26,167	25,958	-	58,819
Cleveland	29,926	26,030	33,165	35,181
New Orleans	23,254	22,978	30,185	52,316
Newark	40,686	43,977	31,536	34,062
Philadelphia	33,076	54,003	36,602	50,382
Pittsburgh	39,733	20,769	22,975	37,224
San Francisco	19,355	20,528	16,656	38,131
San Diego	177,467	144,709	128,976	158,179
Buffalo				49,831[a]
Portland				65,034[a]
Sacramento				138,888[b]

[a]1987 data.
[b]Sacramento data from interview; annual miles estimated.

Operations Support Personnel

Table 3 presents the ratio of revenue vehicle operators (FTE) to operations support and supervisory personnel (FTE), a category that includes schedulers, dispatchers, and administrative personnel specifically assigned to the operating departments. It may also include car hostlers, but these employees may alternatively be categorized as vehicle maintenance support personnel.

This table is based on the schedule of labor equivalents presented in Table 3.14 of the annual Section 15 reports. The values range from a high of 8.33 operators per support and supervisory FTE, reported by Philadelphia in 1985 (which appears out of line with Philadelphia's other years), to a low of 0.92, reported by Pittsburgh in 1985. All systems, except San Diego, report operator-to-support and -supervisory ratios that fluctuate greatly, often by as much as 50 percent, between fiscal years.

The planners of the new system under study intended to incorporate operating personnel in an existing transportation division so that no additional support staff would be required. Supervision was to be provided by existing on-street supervisory staff. Operations were to be controlled by wayside signals and the rule book. Switching was to be operator-controlled, except in the yard during weekday peak periods. Neither mimic boards nor central control posts were contemplated. As a result, it was determined that only one additional transportation support/supervisory position was required for this particular application. It was also determined that if the LRT system under study were to operate as a stand-alone, seven FTE transportation support and supervisory staff positions would be required.

Vehicle Maintenance Labor

Table 4 reports the productivity measure of annual vehicle-miles per revenue vehicle maintainer. The values for this measure were calculated on the basis of the labor equivalents presented in Table 3.14 and the annual vehicle-miles reported in Table 3.16 of the Section 15 reports. The range is extremely wide, from more than 175,000 annual vehicle-miles per maintainer in San Diego's best year to as few as 20,000 in Pittsburgh and San Francisco in their worst years.

Explanations for the width of the range include differences in labor agreements; the technical quality and training levels of the work force; different equipment, servicing cycles, and maintenance requirements of the fleets in various cities; and differences in the overall condition and reliability of the various fleets. Two other factors that may help explain the unusually high productivity reported for San Diego are the relative "youth" of the fleet and San Diego's relatively heavy

TABLE 5 CARS PER ELECTROMECHANIC

System	Fleet Size	Electromechanics	Cars per Electromechanic
Sacramento	26	7[a]	3.71
Newark	24	8	3.00
Portland	26	13	2.00
San Diego	30	18[a]	1.67
Buffalo	27	21	1.29

[a]Plus supervisor.

reliance on contract maintenance (indicated by the use of ~14 percent of their reported maintenance expenses for purchased services).

The alternative approach used for the new LRT study involved establishing a measure of vehicle maintainers to fleet size, expressed as cars per electromechanic. The telephone interviews included a fairly detailed investigation of the staffing plans and job descriptions for maintenance department staff, combined with measures of time to perform typical tasks (e.g., nightly inspection, primary mileage-based preventive maintenance inspection). For the new system, a scenario describing the work that would be done in house and the work that would be contracted out was also developed.

Table 5 presents the cars per electromechanic ratio for five properties. The ratio ranged from a high of 3.71 vehicles per vehicle maintainer to a low of 1.29. The telephone interviews also revealed widely varying job descriptions:

- On one property, vehicle maintainers also move cars around the yard to prepare the morning lineup and, in effect, perform a nightly running systems check as they do so.
- On another property, some of the staff counted as vehicle maintainers for the Section 15 report are semipermanently assigned to repair fare vending and change-making machines, and thus they do not really work on revenue vehicles.
- Some properties still have cars under warranty, so manufacturers' staff members are performing warranty work. One property indicated that they would have to expand car maintenance staff when car mileage reached the point at which a general inspection was required.

Within the revenue vehicle maintenance operation, however, there appeared to be somewhat more consistency in the amount of time required for specific tasks. Thus a number of properties reported that the nightly systems check took about 20 minutes per car and that the first mileage interval inspection (typically performed at 3,000–4,000 miles) took about 12 work hours. This information was combined with assumptions about the car configuration and a calculation of annual fleet mileage to calculate inspection labor hours. Inspection labor hours per year were calculated as follows:

- Nightly safety checks (0.33 hours × 26 cars × 365 days): 3,160;
- Weekly pit inspection (0.67 hours × 26 cars × 52 weeks): 910;
- Mileage inspections (4,000 mile intervals): 6,430;
- Total annual inspection hours: 10,500.

This comes to seven electromechanics, on the basis of an assumed 6.8 productive staff hours per worker shift and 220 worker shifts per staff year. The staffing plan ultimately included two additional electromechanics for running repairs that are not covered under warranty.

TABLE 6 VEHICLE MAINTAINERS PER VEHICLE MAINTENANCE SUPERVISOR

	Year			
System	1982	1983	1984	1985
Boston	3.9	3.0	-	1.8
Cleveland	4.4	4.4	2.5	2.3
New Orleans	5.8	6.2	8.2	4.3
Newark	14.0	13.0	14.0	16.0
Philadelphia	2.9	2.3	2.1	1.9
Pittsburgh	1.5	3.8	2.1	2.2
San Francisco	2.2	1.9	2.5	4.8
San Diego	1.5	2.8	2.6	2.7
Buffalo				2.1[a]
Portland				2.4[a]
Sacramento				2.6[b]

[a]1987 data.
[b]From Sacramento staffing plan.

Vehicle Administration/Supervision Labor

The Section 15 staffing table includes a category for FTEs for vehicle maintenance administration labor. Table 6 presents Section 15 statistics for a variety of years and systems. This table, produced from data in Table 3.14 of the Section 15 reports, again demonstrates that productivity measurements (efficiency of supervision, in this case) fluctuate dramatically between systems and even between years in a given system. For 1985, the values range from a high (most efficient) of 16.0 for Newark to a low of 1.8 for Boston.

Supervisory or administrative requirements are a function of many factors, including the number of locations at which maintenance is performed, the hours during which the maintenance facilities are staffed, the system's job classifications and practices relating to monitoring and supervision, and the ability to employ "working foremen" or similar quasi-supervisory staff, to name a few. If Table 6 values were applied to a system with 30 vehicle maintainers, 12.5 supervisory staff would be used for cost estimating purposes if Portland's ratio were applied, but only 6.25 would be used if San Francisco's 1985 ratio were chosen. Development during O&M costing of a staffing structure designed specifically for a new system appears much more likely to yield an accurate result than does use of an average productivity factor from the table.

Vehicle Servicing Labor

Although the Section 15 data include a category for vehicle maintenance support labor, these data were not analyzed in the same way as were data for the other maintenance categories, primarily because the category may include such diverse job classifications as parts clerk, mileage clerk, stockroom clerk, and car cleaner. There is no way to tell from the Section 15 data, however, which categories were included for any given system. It thus appears to be much more appropriate to use a detailed labor buildup approach for O&M costing in this category.

TABLE 7 CARS PER CAR CLEANER

System	Fleet Size	Cleaners	Cars per Cleaner
Newark	24	2	12.0
Portland	26	4	6.5
Buffalo	27	6	4.5
Sacramento	26	6[a]	4.33
San Diego	30	7–10	3.0–4.33

[a]Plus supervisor.

TABLE 8 TRACK MILES PER MAINTAINER

System	Single-Track Miles	Maintainers	Track-Miles per Maintainer
San Diego	41.0	12	3.42
Sacramento	25.6	11	2.33
Portland	28.1	23	1.22
Newark	8.5	20	0.43
Buffalo	12.4	69	0.18

Table 7 presents data for employees engaged in car cleaning on a number of properties, based on the interviews described earlier. The interviews also revealed a significant difference in the level of detailing that different properties plan for their car cleaning: whether cars are washed nightly, how often interiors are mopped and the glass is polished, and so on. The amount of detailing required does not necessarily reflect variations in cleanliness standards because the different properties operate under different climatic conditions and passenger loads.

As previously mentioned, some systems include car hostlers in the maintenance employee count, whereas others include these workers in the transportation department count. It was thus deemed advisable to separate the functions clearly in the interview process and in the productivity measure. The productivity ratios for this category of labor ranged from 12 to 3.0–4.3 cars per cleaner. The latter range was estimated by San Diego, where car cleaning is contracted out; the staffing level is determined by the contractor.

Nonvehicle Maintainers

Nonvehicle maintenance functions include maintenance of power and signals, track, ballast, right-of-way, structures, drainage, fare collection equipment, and communications. Staffing typically includes a line crew, which deals with all items involving electrical power, and a track crew, which deals with all items that do not involve electrical power. In case of need, some systems' labor agreements permit cross-use. Other functions performed by staff in this category may include station platform cleaning, trash pickup along private right-of-way, and maintenance and repairs on the physical plant (buildings, station shelters, etc.). Some properties count the fare equipment repairers as electromechanics and include them in the vehicle maintainer count, whereas others include them in the nonvehicle maintainer category.

Table 8 presents the productivity ratio of track-miles per maintainer for selected properties. The range extends from 3.42 miles per maintainer in San Diego to 0.18 miles per maintainer in Buffalo. The properties that have a large number of nonvehicle maintainers relative to their trackage have underground stations that require extensive and frequent cleaning. Buffalo also uses its nonvehicle maintainers to remove snow along the downtown mall portion of the right-of-way in the winter. The other new properties have relatively simple, basic station stops and no snow-removal duties. Again, averages mask local conditions.

TABLE 9 PEAK VEHICLES PER FARE INSPECTOR

System	Peak Vehicles	Inspectors	Peak Vehicles per Inspector
San Diego	25	12[a]	2.08
Buffalo	23	12	1.92
Sacramento	23	6[a]	3.83
Portland	22	9	2.44

[a]Plus supervisor.

Fare Inspection

A new category for staffing, applicable to systems using the Proof-of-Payment (POP) fare system, is fare inspection. This job classification is not yet reported separately in the Section 15 reports, although it may be included in another staff grouping. New properties have widely differing staffing practices for fare inspection. It is difficult to make comparisons because of differences in the amounts of service provided. For example, Portland and Sacramento currently operate 15-minute headways during midday base hours and 30-minute headways during evenings. Buffalo operates 10-minute headways during midday base hours and 20-minute headways in the evenings. San Diego's fare inspectors are counted in the staff of the Metropolitan Transit Development Board instead of the San Diego Trolley staff, further complicating the analysis. Table 9 presents the number of peak vehicles per fare inspector for four POP systems. The range is from 1.92 for Buffalo to 3.83 for Sacramento, reflecting different levels of enforcement and coverage as well as scheduling. In addition, it should be noted that the selection of the level of enforcement is influenced by the level of fare evasion deemed locally acceptable.

Power Consumption

Table 10 presents information on the average rate of electric power consumption for vehicle propulsion. The indicator, kilowatt hours of propulsion energy consumed per vehicle-mile (kwhr/veh-mi), reflects a variety of factors, including type of vehicle, type of propulsion power distribution and pickup system used, frequency of station stops, average vehicle speeds, terrain, and type of braking system.

This productivity measure, as derived from Table 3.18 of the Section 15 data, exhibits the least fluctuation within systems of all the measures presented, although there is a broad range of values among systems. Lowest power consumption rates are found in New Orleans and San Diego, averaging around 4 kwhr/veh-mi over the 4-year analysis period. By contrast, Boston and Philadelphia rates are typically in excess of 10 kwhr/veh-mi. The relative consistency within systems

TABLE 10 KILOWATT HOURS OF PROPULSION ENERGY PER VEHICLE-MILE

	Year			
System	1982	1983	1984	1985
Boston	14.3	11.1	10.3	10.1
Cleveland	5.2	12.7	9.0	6.1
New Orleans	4.5	4.0	4.0	4.0
Newark	6.2	7.2	6.8	6.9
Philadelphia	9.8	10.3	10.5	11.9
Pittsburgh	8.0	10.6	7.4	8.9
San Francisco	12.6	12.7	6.4	9.6
San Diego	4.3	4.0	4.7	4.5
Buffalo				11.8[a]
Portland				7.2[a]

[a]1987 data

can be partially attributed to the lack of ambiguity in the measure. By contrast, measurements of labor efficiency are much more subject to definitions of terms and potential ambiguities in staffing categories.

CONCLUSIONS

Productivity-based models for O&M costs in LRT operation have tended to depend on productivity factors inferred from Section 15 data. These data have proven to be highly variable over time within individual systems, as well as over systems within a given year. Furthermore, the staffing categories are subject to different interpretations, so that strict comparability cannot be assumed among systems. Contracting out, different labor practices, different forms of organization on various properties, and different operating scenarios all combine to make the use of Section 15–based productivity factors somewhat unreliable.

An alternative approach is to use a resource buildup method that relies on a detailed O&M plan that lends itself to fairly detailed staffing conjectures. The alternative productivity factors presented in this paper are examples of the application of this approach, which is capable of being much more system-specific in its productivity factors and hence can produce more accurate O&M cost estimates. Such issues as the integration of the LRT operation into an existing structure versus its operation as a stand-alone system will have significant bearing on staffing and hence O&M costs. These issues are far more accurately handled by the alternative approach presented here than by use of averages derived from Section 15 data.

REFERENCES

1. U.S. Department of Transportation. *Procedures and Technical Methods for Transit Project Planning*. UMTA, U.S. Department of Transportation, September 1986.
2. J. M. Holec and R. L. Peskin. Use of Productivity Measures in Projecting Bus and Rail Transit Operation Expenditures. In *Transportation Research Record 797*, TRB, National Research Council, Washington, D.C., 1981, pp. 40–49.
3. *Transportation Research Record 961: Transit Performance Evaluation and Auditing*. TRB, National Research Council, Washington, D.C., 1984.

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