Application of a Transit Maintenance Management Evaluation Procedure

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ABSTRACT

The application at the Tidewater Transportation District Commission of a framework for evaluating a transit agency's maintenance program is described. This method views the maintenance department's mission as a set of management activities that are associated with functional tasks that comprise the total bus maintenance process. A structured data collection procedure was developed and used to provide the information necessary to perform the analysis. A step-by-step discussion of each of seven management elements cites the data used for the analysis and interprets measures of the level of activity provided. Utilization of Section 15-type data supplements the management unit evaluations to provide an overall measure of the maintenance operation's effectiveness, particularly in terms of vehicle miles per road call and vehicle maintenance cost per vehicle mile. The study results are presented as a summary matrix that shows general performance patterns. This application provides transit agencies with a guide for using the method. The framework suggests promise for promoting comparability among transit maintenance departments.

A practical method for evaluating a transit agency's maintenance program has been developed (1,2). This approach to transit maintenance management views the maintenance department's mission as a set of management activities that are associated with the functional tasks that comprise the total bus maintenance process as shown in Figure 1. The influence of environmental features and organizational characteristics is represented as "external factors" in Figure 1.

Table 1 gives levels of each activity for increasing levels of sophistication and resource dedication. When a transit agency's maintenance program is evaluated, its performance for each level is assigned a value (A to D) along a spectrum. In general, the basic arrangement of A represents a package appropriate for small transit systems. As an agency moves toward D, its operation becomes elaborate and complicated, as represented by larger properties. The derivation of this framework for evaluating bus transit maintenance operations has been described elsewhere (1,2). The rationale for the set of activities used and the established levels are included in the earlier publications on this method. Described in this paper is an application of maintenance management evaluation techniques in the Tidewater Transportation District Commission (TTDC). This agency was selected because it lies within the size range of a small-to-medium property and because it was willing to cooperate with the study team.

The TTDC is a special administrative arrangement that provides public transportation services for five municipalities (Norfolk, Virginia Beach, Portsmouth, Chesapeake, and Suffolk) in the southeastern corner of Virginia. There are 180 motorbuses in the agency fleet, and the agency has an extraordinary commitment to vanpools and minibuses (another 165 vehicles). The annual cost for the bus operation in FY 1983 was $13,274,422, 19.8 percent of which was dedicated to bus maintenance.

A structured data collection procedure was developed and used to provide the information necessary to perform the analysis (1). The evaluation form was completed through the following three levels of effort:

1. A general analysis of available information;
2. A preliminary visit and discussion with various TTDC officers; and
3. A process of feedback and review during the final stages of a site visit, during which contacts were made with the assistant superintendent of equipment I, the assistant superintendent of equipment (and maintenance training) II, the administrative assistant, an equipment office representative, the purchasing manager, a transportation planner, and a computer operator.

The following discussions address how information is translated into the analysis framework. The evaluation requires establishing values for the elements in a row of Figure 1. This case study is to be considered a starting point for (a) practical application of the method, (b) motivation toward using the framework for peer comparisons (descriptive information), (c) assessing the potential for refining the subjective measurement system into an objective technique, and (d) suggesting further research to relate the rating information to system performance.

DESCRIPTION OF COMMUNITY AND EXTERNAL CONDITIONS

From a review of environmental factors external to the organization, pertinent information can be summarized for the left column of the matrix of Figure 1. The TTDC serves an area characterized by a

- Large community (900,000),
- Moderate population density,
- Moderate-to-light transit reliance,
- Flat terrain,
- Mild-to-warm, variable climate, and
- Moderately priced labor market.

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DESCRIPTION (EXTERNAL FACTORS)	WORK ASSIGNMENT	MAINTENANCE SCHEDULING	WORKFORCE DEVELOPMENT	LABOR ALLOCATION	INVENTORY MANAGEMENT	EQUIPMENT MANAGEMENT	INFORMATION SYSTEMS
BASE CASE: Small Community (50,000) Dispersed Community Light Transit Reliance Flat Terrain Warm, Moderate Climate Inexpensive Labor Market New Road Surfaces 15-Bus Fleet 72 Hrs. Revenue Service/wk. Homogeneous Fleet Abundant Capacity in Facility Nonunionized Workforce	A	AorB	AorB	A	A	A	A
Moderately Small Community (120,000) Dense Community Moderate Transit Reliance Flat Terrain Moderate Climate Expensive Labor Market New Road Surfaces 40-Bus Fleet 90 Hrs. Revenue Service/wk. Heterogeneous Fleet Abundant Capacity in Facility Unionized Workforce	B	B	B	BorC	BorC	B	B
Moderately Large Community (500,000) Dense Community Moderate Transit Dependence Flat Terrain Warm, Moderate Climate Expensive Labor Market New Road Surfaces 200-Bus Fleet 105 Hrs. Revenue Service/wk. Heterogeneous Fleet Abundant Capacity Facility Unionized Workforce	C	BorC	C	C	C	C	C
Large Community (1,000,000) Dense Community Moderate Transit Reliance Flat Terrain Warm, Moderate Climate Expensive Labor Market New Road Surfaces 450-Bus Fleet 120 Hrs. Revenue Service/wk. Heterogeneous Fleet Abundant Capacity Facility Unionized Workforce	D	CorD	D	D	D	D	D

FIGURE 1 Composite profiles of maintenance departments.

Of this group, the factors that would most influence maintenance performance are the almost ideal operating conditions of mild weather and flat terrain, and these factors are not significantly mitigated by any adverse conditions in the labor market or by road conditions.

The organization pursues its objectives through a management-by-objectives system that stresses that, at the highest level, the budget deficit should not exceed $1.00 per passenger. The resulting charge to the maintenance department is to support "running equipment as efficiently, economically, and effectively as possible," although the objectives become more specific as they filter down through the organization. Informally, maintenance managers state that "cleanliness and a mechanically stable fleet [not a lot of breakdowns]" are stressed. The bus fleet has to be characterized as diverse, or heterogeneous, with the breakdown given in Table 2.

From a review of organizational policies, pertinent information can be summarized to complete the left-hand column of the matrix as follows:

- A 180-bus fleet, 129-bus peak fleet,
- 154-hr of revenue service per week,
- A diverse fleet,
- An abundant capacity in facility,
- A new fleet, 6.0-year average age,
- A unionized work force, and
- A total of 28 percent spare vehicles.

WORK ASSIGNMENT

Work assignment throughout the day is executed in the following sequence. Buses receive a brief inspection by operators at the beginning of the run, and extended preventive maintenance inspections take

TABLE 1 Maintenance Activity Level Definitions

	Level			
Activity	A	B	C	D
Work assignment	Contract out heavy repairs, in-house inspection; first-come, first-served.	Some heavy repairs in-house; maintain and repair quickest item first.	Spectroanalysis augments inspection; priority for scheduled work over breakdown.	All repairs in-house.
Maintenance scheduling	No scheduled inspections on most items.	Manufacturer's inspection guidelines.	Individually tailored inspection intervals.	Scheduled replacement intervals.
Work force development	No training, seniority promotion, no incentives, no work standards.	Outside training; nonmonetary incentives.	Merit promotion, monetary incentives, work standards.	In-house training.
Labor allocation	All crews responsible for all duties; no specialized mechanics; no specialized crews; no specialized teams; one shift.	Specialized mechanics; two shifts.	Specialized crews; three shifts.	Specialized teams.
Inventory management	No formal structure except minimum safety levels.	Manual systems; defined order quantities; defined reorder points; safety stock defined through service levels.	Computerized system.	Computerized system directly integrated with maintenance scheduling; order quantities and reorder points contingent on scheduling.
Equipment management	Low capital intensity.	Moderate capital intensity with minimum special equipment.	Moderate capital intensity with selected special equipment items.	High capital intensity with specialized equipment.
Information	Aggregate; manual; direct entry; nonintegrated.	Automated; microcomputer.	Micro/mini; indirect entry.	Disaggregate information; automated; mainframe computer; integrated.

TABLE 2 TTDC Motor Bus Fleet

Number	Year	Vehicle Model
47	1973	Grumman Flxible 53102
10	1978	Bluebird
72	1979	Grumman Flxible 53096
20	1980	GMC RTS-II
7	1981	Ford "Trolley"
13	1983	Flxette
9	1983	GMC "Trolley"
2	1980	Chevrolet Transliner

place chiefly during the day (the first shift is from 7:00 a.m. to 3:30 p.m.), unit overhaul and other shop activities take place during the day (7:00 a.m. to 3:30 p.m.), running repair (which responds to breakdowns and operator-generated or inspection-generated work orders) takes place during all shifts (7:00 a.m. to 3:30 p.m., 3:30 p.m. to 12:00 midnight, and 10:30 p.m. to 7:00 a.m.), and the servicing operation (6:00 p.m. to 2:00 a.m.) occurs between shifts.

The work load is determined by the inspection intervals (see section on Maintenance Scheduling elsewhere in this paper) and the resulting work orders, and by in-service breakdowns or operator complaints. Essentially, six buses per day receive a preventive maintenance inspection. All vehicles pass through the daily servicing cycle, which averages 15 to 20 min per vehicle. During this cycle, the farebox is removed, oil and transmission fluids are checked, tires and lights are checked, the fuel tank is filled, and the vehicle is vacuumed, washed, and parked.

Shop activities consist of unit overhaul (rebuilds and other work that requires removal of components), body work, and painting. All these activities take place in the first shift (7:00 a.m. to 3:30 p.m.).

The preceding describes the routine assignment of work tasks. However, events in the day are frequently not routine and certain issues must be confronted in the assignment of work tasks. One such issue is contracting work outside the agency. Some repair tasks are contracted out, but it is the policy of the maintenance department that no item be automatically contracted. Essentially, only 1 percent of engine and transmission work is contracted out at times when shops become overloaded (when shortage occurs in specialized personnel for those time-consuming tasks); otherwise, there is no contracting. In cases such as seasonal peaks of air conditioning repair work, the policy of the department is to use overtime instead of contracting, so as to ensure control over operations.

Another issue of work assignment is whether to execute inspection procedures entirely on-site. The department does administer regular on-site inspections, but, in addition, some oil analysis is conducted by an outside firm, which effectively amounts to contracting some inspection. In this case, oil spectroanalysis is performed by the vendor that supplies oil to the department. This service is furnished free to advise on the condition and performance of oil stocks. The officers believed that this service did not appreciably assist or augment on-site inspections. They suggested that it was accepted because it was a free service and the results were not incorporated into the inspection routine. Maintenance work is scheduled at the beginning of the day subject to change as events occur. However, the department does try to schedule the heavy work of the unit overhaul shop as much as 1 week in advance.

Last, the rule of queue discipline determines the sequence of work of the maintenance shop. Maintenance duties at the TTDC are largely dispatched on the basis of "quickest tasks to be done first." In the running repair shop, a secondary rule was also suggested: "put new buses on the road before old buses" to promote attractiveness of service.

A summary of the preceding discussion can be compared to the performance scale for work assignment given in Table 1. The TTDC does almost all heavy repair in-house, which would place the TTDC at a position a degree higher than C on the spectrum of work assignment. The TTDC also conducts some off-site spectroanalysis inspections, but the spectroanalysis plays a minor role in operations, so this feature would place the TTDC a little lower than C on the spectrum. The queue discipline policy of "quickest items first" indicates that operations have not yet attained the size where scheduling difficulties would make "scheduled work over breakdown work" the dominant policy. Thus, the TTDC's queue discipline would place it on the B point of the spectrum. In considering all of the factors, and giving weight to the first point of minimal contract work, the TTDC's collective work assignment policy can be summarized as C.

MAINTENANCE SCHEDULING

The primary policy decision that a maintenance department faces concerns the balance between a preventive maintenance schedule and attending to maintenance needs that result from breakdowns. The TTDC maintenance department has opted to select a preventive maintenance schedule, which revolves around basic inspection intervals of 6,000 mi for most vehicle models (or units of 3,000 mi for the smaller "trolleys" and Flxettes). This schedule is adhered to conscientiously, except for some special seasonal campaigns, such as air conditioner and alternators in the spring and water pumps and heaters in the fall. Furthermore, prerun (check water, windshield wiper, signals, accident damage, and loose mirrors) and postrun inspections are executed by drivers on each vehicle run.

The specification of mileage for inspection intervals is crucial. The TTDC bases its schedule primarily on the guidelines suggested by manufacturers, although this base is frequently modified to suit agency experience. As an example of adjustment, the manufacturer of the smaller Flxettes recommended 6,000 mi as a basic unit for inspection. Using this schedule, the TTDC experienced repeated problems, such as oil leaks and dirty transmission fluids. The department reacted to this experience by adjusting its basic inspection interval to 3,000 mi. The new interval was arrived at through an informal process of judgment and analysis of records. Maintenance officers judge that since this adjustment was made, the system has worked fine. The department estimates that from 8.5 percent to 10 percent of items that are listed for inspection have received revised interval values.

The TTDC maintenance department has not established a strict program for scheduled replacement of components, however. Major components are frequently rebuilt when they are judged to be performing poorly, but precise mileage intervals are not observed. In reevaluating inspection intervals or arriving at a decision to pull and rehabilitate a component, the department refers to monthly computer reports. These reports display incidents of in-service troubles, either according to individual bus vehicles or according to component type. When it is judged that extraordinary problems are occurring with a component, action can be taken either to rebuild it or to revise the inspection interval.

At the time of the site visit, most of the maintenance scheduling had been computerized. The computer information system traces which vehicles are approaching their inspection time by comparing the number of miles since the last inspection with the basic inspection interval (usually 6,000 mi).

A comparison of the TTDC maintenance department's long-term scheduling policies with Table 1 indicates that the TTDC has opted to implement a preventive maintenance inspection system, which is to be expected from all but the smallest agencies. In developing the inspection schedule, manufacturer's guidelines for mileage intervals are used as a base, but this base is adjusted considerably according to departmental records and judgment. The TTDC maintenance department does not, however, employ statistical studies to establish interval values, but has instead found success with an informal analytical process. The TTDC maintenance scheduling policy has not emphasized optimal intervals for automatic replacement of components instead of inspection intervals. Because of the informal analytic process that accompanies interval values, and because scheduling has not been taken to the extreme of studying optimal replacement intervals, one would place TTDC's maintenance scheduling policy at C on the spectrum of Table 1.

WORK FORCE DEVELOPMENT

The personnel functions of the maintenance department are guided chiefly by labor union agreements and explicit written procedures. The subjects that are considered in this evaluation are recruitment policy, training programs, criteria for promotion, discipline and grievance procedure, motivation programs, and work standards. At the entry level, no one is hired without mechanical experience despite a low starting wage ($4.33/hr) and despite the fact that some career paths (bus cleaners, for example) do not make great use of a mechanical background. The training policy is such that once an employee is recruited, he receives unsupervised on-the-job training, supervised on-the-job training, some classroom training with industry manufacturers, and some on-site classroom instruction.

When positions above the entry level are to be filled, the department's promotion policy takes effect. Senior positions are filled only from within the organization. As soon as a senior position opens, the department goes through a bidding process whereby the job is awarded to that individual who has the most seniority for the job classification. Merit tests are not applied at each level of advancement, although merit is considered in the form of a review of an applicant's records (e.g., absenteeism and discipline problems).

The TTDC maintenance department has developed incentive programs. One fundamental incentive is provided through differential pay scales. Many transit agencies are hindered by pay levels that provide little difference between entry level and the most senior positions, but this is not the case for the TTDC. The lowest pay for the lowest positions is $4.33/hr, and the highest pay for the highest positions reaches $10.94/hr. Thus, the prospect of promotion and accompanying pay raises provides a strong financial incentive for TTDC maintenance personnel to seek advancement. Progressing from the lowest to the highest pay scale would provide a pay increase of 153 percent, which is a greater differential than many agencies offer.

Other pay incentives are a premium of $0.15/hr for working the 10:30 p.m. to 7:00 a.m. "graveyard" shift, which is not highly effective in attracting interest in the shift, and the time-and-a-half pay premium for overtime, which is effective. Seniority is the key criterion for the assignment to shifts. Senior workers get first preference in shifts, which amounts to the least senior workers staffing the second and third shifts. The system for assigning overtime gives equal consideration to all workers; seniority is not a factor. Priority for overtime is assigned according to a rotating board system in which the name at the top of the list is offered first choice.

The standard for comparison is given in Table 1. Because the development of the maintenance department's training program relies heavily on outside training and on-the-job experience, the TTDC's training program falls between B and C on the spectrum. The seniority system of promotion would place the TTDC at B, and special monetary incentives puts it between B and C. The absence of monitoring task completion times (no work methods or standards) places it at B or lower. Altogether, the composite work force development program of the TTDC could be summarized as B or B/C, with noticeably low development of training, promotion, and work methods policies.

LABOR ALLOCATION

According to Fiscal Year 1983 Section 15 reports, the TTDC's motorbus transit operations had 67 maintenance labor equivalents or 2.70 vehicles per maintenance employee. These figures compare favorably to the 1982 Section 15 averages for the industry. Motorbus fleets of TTDC's size bracket (100-249 buses) average 2.4 vehicles per maintenance employee, although industry-wide averages are 1.8 vehicles per maintenance employee. The TTDC's favorable employee-to-vehicle ratios may be attributable in part to the ratio of spare vehicle to required vehicles. Reliance on overtime is commonplace in the maintenance department, but it is controlled. Overtime hours are estimated at 6.6 percent of regularly scheduled hours.

The TTDC's evaluation relative to Table 1 is as follows. It clearly supports three shifts of maintenance operations, thus placing it toward the C/D range on the spectrum. Inspection crews, furthermore, are effectively separated from repair crews. However, road crews are not regularly staffed but are improvised according to worker availability. Thus, crew organization at the TTDC would be squarely placed at C on the spectrum. Although functional teams are nominally set up in the maintenance department, the separation is flexible over the long run (new sign-ups every 6 months) and very flexible over the short run (idle team members being temporarily assigned to other productive tasks). Thus, the TTDC's policy of administering specialized teams would place it just slightly above C on the spectrum. Individual mechanics (such as electricians and welders) do receive specialized status and training, thus the TTDC's orientation of mechanics would qualify as "specialized" and would place the TTDC in the C/D range of the spectrum. Altogether, the combined profile of the labor allocation system would be classified as C: specialized mechanics, somewhat specialized crews, minimally specialized teams, and three shifts.

INVENTORY MANAGEMENT

The inventory system of TTDC is one of the sequestered stockroom with the flow of stock being directly monitored by purchasing personnel, both at the point of receiving and at release for work orders. Parts are ordered by the purchasing office when a computer review indicates that the number on hand is at or below the minimum level. Orders are entered on the part profiles on the computer, and they remain on an outstanding status until the parts arrive. The receipt of stock is also entered on the part profile in the computer, and the outstanding status is amended. The stock is placed in the stockroom and is issued when maintenance employees present work order release forms.

The TTDC employs a reorder point system. Projected usage rates for parts are based on records when possible, and the reorder point for parts is generally 30 days' worth of on-hand inventory. Order quantities are generally 90 days' worth of stock--but this order quantity may be larger if an exceptional volume discount is available. Thus, fixed order quantities are established for each part, but these quantities are "recommended rather than mandatory." Because parts are ordered according to usage, orders are issued at irregular intervals and are not placed at predetermined intervals.

The preceding description applies to all parts costing over $2.00. For the many high-volume, low-cost parts (such as screws, nuts, washers), storage is provided outside the stockroom, in bins on the garage floor. Each of these "pink tag" items occupies a bin, and the bin stock is simply regulated by "eyeballing." When the bin is nearly empty, it is replenished from bulk storage in the storage room. Except for the matter of storage location and the requisition process, the inventory cycle for these low-cost items is similar to that for other stock.

At present, the inventory system is monitored both manually and by computer. The manual component consists of request forms (work order release forms that later are entered into the terminal), purchase order forms, copious vendor records, and 97 interchangeable "strip files." The computerized component consists of a profile of each part, which provides the following information:

- Part number assigned by the TTDC,
- List of vendors who supply the part, with preferred (lowest priced or fastest fulfillment) source listed first,
- Order point for part,
- Order quantity for part,
- Lead time for part order,
- On-hand inventory,
- On-order inventory, and
- Cost of part.

Certain measures of performance for the TTDC's inventory management are available. The total parts inventory taken on Sept. 29, 1984, showed a value of $567,800, which amounts to $3,138 per vehicle. Furthermore, stock-outs occur on the average of three or four times a day. This incidence is greater than that for the previous year, and it is seen as a problem. But the increase in stock-outs may be due to the diversity of the TTDC's fleet or the burden of maintaining both manual and computerized information systems during the trial period. Overall, the performance of the inventory office is perceived as sound.

The TTDC inventory can be summarized as computerized, despite the many manual procedures that are being carried through the trial period of the computer system. The computerization of inventory would place the TTDC at C on the spectrum. The agency also has a formally developed inventory cycle using reorder points and order quantities. The determination of these quantities remains somewhat informal, as does the practice of incorporating safety levels of stock into the system. This array of features places the TTDC at the overall C level of development. The system is below the D level of development because of the informal determination of order points, quantities, and safety levels, and because the inventory computer program has not yet been directly integrated with a maintenance scheduling computer program.

EQUIPMENT MANAGEMENT

The maintenance department carries most of the equipment generally found in larger agencies, such as automatic bus washers, large bus vacuum systems, automatic farebox removal equipment, transmission and engine stands, heavy-duty press, brake lathe and grinder, transmission test stand, valve body tester, and TIG and MIG (tungsten and metal inert gas, respectively) welder. However, the department still does not possess its own dynamometers, frame straighteners, shapers, or mill. There was no strong indication among officers that these items are necessary, although some, like dynamometers, were regarded as "nice to have."

Considering the equipment that has been identified at the TTDC, the agency's maintenance department should be classified as significantly capital intensive. It possesses the equipment necessary to execute almost all maintenance operations on-site (less than 1 percent of work is contracted out--see section Work Assignment elsewhere in this paper), but it still does not have some highly specialized equipment (such as dynamometers). In conclusion, the TTDC equipment management system can be summarized as C/D on the spectrum.

INFORMATION SYSTEMS

As indicated previously, the TTDC maintenance department relies on both manual and automated information. At present, there is a significant overlap of the two, but, in the future, more and more reliance will be placed on the automated system, as more program features are brought on-line and as present computer programs prove themselves. The computer system utilizes minicomputers with several terminals available in the bus maintenance facility. The software is a "turnkey" system supplied by a vendor who acts as a consultant in programming new features or attending to problems. Although minicomputer capabilities are broad and execution occurs rapidly, the TTDC's information program can be distinguished from other, more elaborate, automated systems in a number of key ways.

First, the level of detail in the TTDC's maintenance information system is still somewhat aggregated. Specifically, two key benchmarks of information disaggregation are not present. The TTDC does not as yet track and analyze individualized work time records of personnel on the computer--nor does it do so manually. The TTDC is, however, planning to introduce such a program "perhaps in a year or so." Second, failure histories of mechanical components are not kept. Although the monthly printout generates a record of breakdown failures related to specific components, it does not record inspection-generated observations of component failure. Failure information is permanently recorded in manual records, but not in a form that is easily retrieved. Although the TTDC is considering putting all past records on computer storage, such a transcription will be time consuming. If such a system were ever brought on-line, there would be good possibilities for the analysis of inspection intervals based on precise historical data.

In another sense, the department's automated information system is a simple one in that, as yet, only specific maintenance personnel (clerks and administrators) interface with the computer terminals. Terminals are not present at work sites nor are portable recorders employed at work sites. Thus, all information generated from work sites must still be recorded indirectly (i.e., be entered on paper forms to be input later to a terminal by a clerk).

Last, the TTDC has not implemented a system for integrating information programs. The maintenance department employs computer programs for monitoring inspection schedules and inventory, but these programs remain independent of each other. Officers indicate that they are trying to implement a system where the occurrence of certain parts needs will automatically be tied to parts requisition. However, such an integrated information system is extremely advanced for the industry, and it is not likely in the TTDC's immediate future.

The maintenance department's information system can be summarized as using aggregated information, minicomputer hardware, and indirect entry. This configuration comes closest to the C level on the spectrum, with the indirect data entry being a notable exception. Although this exception is significant, the TTDC information system is on the verge of pursuing the disaggregation of worker time information and, in general, supports a fairly sophisticated reporting system. Therefore, the TTDC's information system could be summarized as being between B and C, and as favoring C somewhat.

MONITORING AND EVALUATION

The evaluation framework used in this paper focuses on general measures that can be obtained from Section 15 information, with primary emphasis on the measures of vehicle miles per road call and maintenance cost per vehicle mile. The values are presented in Table 3 for fiscal years 1981, 1982, and 1983. For each year, the values for the TTDC are presented; but, in the last year, comparative information is lacking.

The TTDC's vehicle miles per road call improved slightly from FY 1981 to FY 1983, but, even so, values were less than the average for its class size for 1981 and 1982, and there is every reason to believe that the 1983 data would bear the same relationship. Based on the preceding values, the TTDC's performance may be somewhat unfavorable, although further considerations must be weighed.

Interpreters should be aware that the measurement of vehicle miles per total road calls may still include some factors that are out of the maintenance department's control. Nonmechanical road calls (as distinguished by Section 15) may account for a significant number of road calls, and, by definition, this category of road calls (bus vandalism, illness on buses, farebox problems) may not be a direct responsibility of vehicle maintenance. A general interview with the assistant superintendent of equipment I indicated that nonmechanical road calls may have been an exceptional problem and, therefore, further investigation was conducted.

When performance was adjusted to reflect vehicle miles per mechanical road call only, the TTDC's per-

TABLE 3 TTDC Evaluation by Fiscal Year

	FY 1981			FY 1982			FY 1983
Evaluation Category	Agency	Class	Industry	Agency	Class	Industry	Agency
Vehicle miles per road call	1,386.7	1,687.2	1,461.5	1,453.4	1,748.2	1,265.2	1,450.9
Vehicle maintenance cost (cents) per vehicle mile	34.6	41.7	58.8	36.8	47.6	66.7	50.3
Vehicle miles per mechanical road call	1,947.6	2,095.9	1,850.0	2,195.5	2,372.0	1,554.3	2,292.1

formance improved. The value of miles per incident increased considerably each year (from 1,947.6 to 2,195.5 to 2,292.1). However, in the latest available year for peer comparison (1982), the value still compared unfavorably to the class size average. But one should also note that the TTDC's value of vehicle miles per mechanical road call is above the industry-wide average for both 1981 and 1982. Thus, indications are that the TTDC maintenance department's road call performance is acceptable, but it remains an area to consider for improvements.

The TTDC's performance in vehicle maintenance cost per vehicle mile exhibits a trend that is the opposite of its road call performance, however. In 1981 and 1982, the maintenance cost was low, at 34.6 and 36.8 cents per vehicle mile, respectively. In comparison to both class size and industry averages, the TTDC delivered its services at an impressively low cost. However, in 1983, that status changed; the cost figure jumped to 50.3 cents per vehicle, which was at or just below the class-size average, and which certainly exhibited a sharp rise from the 1981 value of 34.6 cents.

Surely, a small part of this cost rise was attributable to inflation, but further investigation is necessary. Likely causes are increased fleet diversity with increasing emphasis on smaller and "trolley-type" buses, which require more frequent inspection and repair; increased inventory costs associated with fleet diversity; farebox problems; and the burden of maintaining overlapping manual and automatic information systems during the computerization trial period. Nevertheless, the TTDC's low base wage must be regarded as extremely favorable for low-cost operating expenses, and the recent growth in expense must be explained in the light of this advantage.

In conclusion, it might be observed that both road call and cost performance have been moving from extreme values toward more conventional, central values over the 3 years. The TTDC maintenance department experiences a road call incidence within acceptable levels, and it appears to enjoy a cost schedule that is slightly better than acceptable levels. It might also be suggested that some tradeoff has existed between these values; perhaps vehicle miles per mechanical road call has been improved through an increase in vehicle maintenance cost per vehicle mile. However, such an assertion requires further investigation. The most important outcome is to recognize the values of these two measures, their relationship to other values in the industry, and their trends. The decision as to whether these values are acceptable remains one of policy.

CASE STUDY SUMMARY

Based on the review of the different categories, the TTDC maintenance department is shown in Figure 2. Through this summary, general patterns and relationships are shown. Furthermore, the TTDC's maintenance department could be compared with the maintenance departments of other agencies described in the same framework.

Figure 2 indicates that the TTDC operates a fairly large fleet of 181 vehicles and serves a comparatively large urban area. Furthermore, it has many favorable conditions affecting bus maintenance: the fleet is young, the present maintenance facility

Description	WORK ASSIGNMENT	MAINTENANCE SCHEDULING	WORK FORCE DEVELOPMENT	LABOR ALLOCATION	INVENTORY MANAGEMENT	EQUIPMENT MANAGEMENT	INFO SYSTEMS	MONITORING & EVALUATION
Large community (900,000)								
Moderate population density								
Moderate-to-light transit reliance								
Flat terrain								1450.9 vehicle miles per road call.
Mild-to-warm, variable climate								
Moderately priced labor market	C	C	B	C	C	C/D	B/C	2292.1 vehicle miles per mechanical road call
180 bus fleet, 129 peak fleet								50.3¢ vehicle maintenance cost per vehicle mile.
154 hrs. revenue service/wk								
Heterogeneous (diverse) fleet								
Abundant capacity in facility								
New fleet (5.9 yr. avg. age)								
Unionized workforce								

FIGURE 2 TTDC profile.

accommodates operations easily, ample spare vehicles are provided, and terrain and weather are nearly ideal. Countering these positive conditions are the diverse character of the fleet and an almost around-the-clock delivery of revenue service. Overall, the conditions appear to be quite favorable, but each management activity area is differently affected by each listed characteristic. For instance, the heterogeneous character of the fleet places special burdens on maintenance scheduling, work force development (training), and inventory management.

Using Figure 2, one can compare the development of the different management areas with the expected impacts. For instance, one might expect a general level of development approaching C for operations of 180 buses--a size of operations that is considerably far along the size scale of 15 to 500 considered in this study. In general, this pattern is strikingly borne out: the array of C-C-B-C-C-C/D-B/C focuses around the C level; but the condition of a heterogeneous fleet may lead one to expect a fairly developed structure for training when, in fact, work force development is indicated as somewhat modestly developed--at level B. From this observation, a reviewer may wish to probe further into the details of the work force development system, to judge whether the arrangements are properly matched to the needs of the agency.

The performance of one management area can also be directly compared with another. For instance, it would be unusual for an inventory system to be out of step with the development of an information system. If such a situation were observed, then perhaps a reviewer would wish to examine these two areas of management activity together. In the case of the TTDC, the development of inventory management policies (C) does appear to be closely matched with information system development (B/C).

Finally, Figure 2 offers some key, general measures for the performance of the maintenance department. If the values appear disappointing, then a close look may be warranted at the possibility of either overdeveloped or underdeveloped areas of the maintenance management system. For instance, a high maintenance cost per vehicle mile might cause a reviewer to consider whether an equipment management system is overdeveloped (i.e., carrying too much specialized equipment when the size of operations or some other factor may argue for relying more heavily on contracting work out for specialized tasks) or underdeveloped (i.e., arguing for the acquisition of further specialized equipment so as to achieve economies or to increase control by reducing reliance on outside contractors).

Performance measures can also be interpreted in another way. Particularly strong values may caution a reviewer to take moderate action on perceived imbalances in a management area. For instance, in another study, one large agency (650 buses) was documented as having a maintenance information system that would measure A in this framework (3). Nevertheless, the performance of the maintenance department was strong according to indicators, due partly to strong informal practices that had been built up over time. Although the A level of development in information appears to be inappropriate for that agency, any actions that might upset the present informal systems should be carefully considered.

In the case of the TTDC, the performance measures of vehicle maintenance cost per vehicle mile and vehicle miles per mechanical road call both approach intermediate values. Therefore, no immediate action is prompted by either measure, but recent trends might be kept in mind: that is, maintenance cost has been worsening recently, while mechanical road calls have been improving. Ultimately, the decisions based on performance values will depend heavily on the policies of the agency involved, for that agency will determine which performance values are acceptable.

When the matrix is reviewed collectively, the elements of TTDC's maintenance department appear to be compatible with each other and well-suited to its environmental conditions. The values of performance measures for road calls and maintenance cost indicate acceptable performance, but both measures also suggest room for improvement--especially in light of recent trends of cost and a road call value that still remains somewhat low despite recent improvement.

The array of symbols would indicate that the management activities that should be given further attention are work-force development and information systems. At values of B and B/C, respectively, these levels of development may appear somewhat low for an agency the size of the TTDC. However, the deviation for information systems is slight, and the rating of B/C is not unusual for an agency that has already begun automation of its information system. Furthermore, the TTDC maintenance department appears to be firmly committed to further development of information systems, including the imminent introduction of a monitoring program for worker task times. Therefore, no recommendations appear to be required by the present state of the department's information system. In contrast, the work force development area appears to be a strong candidate for improvement.

Certain circumstances, such as the many vehicle models with newer, complex design features, make special demands on the skill and knowledge of the work force. Furthermore, as more and more new recruits are absorbed into the organization, added burden will be placed on the department's ability to train personnel. The new pay scales will most likely accentuate the need for training, as it cannot be expected that applicants of significant mechanical experience will be attracted by the low wages that are offered to all new recruits. Although some of the problems associated with applicants could be lessened through a revision of the recruitment policies, attention still needs to be directed to the present training structure. A program for monitoring worker task times should also greatly assist the development of personnel.

EVALUATION OF METHODOLOGY

The evaluation method applied in this paper has hypothesized a relationship between selected activities and transit organizational performance resulting from the maintenance effort. Resources are shown in terms of levels for each of seven activities. When a transit agency increases the sophistication of its maintenance effort, the cost per unit served can be expected to rise, but the fleet reliability as expressed in vehicle miles per road call will decrease. This was the case of the results shown in Table 3. Over a 3-year period, as related in the discussion, the TTDC enhanced their maintenance program using automation, modern equipment, labor incentives, and other positive changes. This increased cost was shown in the vehicle maintenance dollars spent per vehicle mile. The enhanced performance was noted by the increase in vehicle miles per road call.

If a broad set of applications similar to that described in this paper were conducted, researchers would have data to study the formulation of relationships between maintenance activity levels and performance. Quantifiable criteria governing each activity level would be desirable. Such criteria could evolve from those provided for this rather subjective application as given in Table 1 into specific measures that are associated with a score between 0 and 100. Such a score could be derived from concepts of the normal probability distribution to indicate Z-scores and associated cumulative probabilities. The Z-score is defined as

$$Z = (x - \mu)/\sigma \quad (1)$$

where

x = measure on a 0 to 10 scale for a transit property,
μ = average peer group measure from sampled properties,
σ = standard deviation of peer group measure, and
Z = normalized maintenance activity level score.

The Z-score is the abcissa value for a standard normal distribution. The Z-value is converted into a probability measure by integrating the standard normal density function.

$$P(X \leq x) = \partial\ 1/2\pi^{1/2} \int_{-\infty}^{(x-\mu)/\partial} e^{-1/2Z^2} \sigma dZ \quad (2)$$

Using tables for the standard normal distribution, Z becomes

$$P(X \leq x) = \phi[(x - \mu)/\sigma] \quad (3)$$

Equation 3 can be converted to a performance score that shows performance relative to the expected measure for the peer group as follows:

$$\text{Performance} = \phi[(x - \mu)/\sigma] \times 100 \quad (4)$$

where performance is the percent of peer properties performing below the operator under consideration on the scale.

The next step is the estimate of an aggregate score for the seven activity measures (Z_i; $i = 1, \ldots 7$). Here, each score would be weighted for the overall score. Then

$$P_T = \sum_{i=1}^{7} W_i P_i \quad (5)$$

where

W_i = weight for ith activity ($o \leq W \leq 1$) $\sum_{i=1}^{7} W_i = 1$, and
P_i = performance score for ith activity.

In addition to the P-score approach, there are the aggregated performance measures, vehicle miles per road call, and maintenance cost per vehicle mile. There are different ways that these measures can be disaggregated and related to the activity level scores. One proposal uses either of the performance measures as a dependent variable and multiple linear regression or a transformed nonlinear form using the seven levels as explanatory variables.

$$Y = b_1P_1 + b_2P_{-2} + \ldots b_7P_7 \quad (6)$$

where

Y = vehicle miles per road call,
b_i = regression coefficients, and
P_i = activity level P-scores.

Or, a single regression on the aggregate score can be attempted as

$$Y = bP_T \quad (7)$$

The preceding are ideas that can be researched along with others to reach the objectives of (a) providing for the numerical measurement of activity levels, (b) calculating combined scores for all activity levels, and (c) relating activity resources to maintenance performance. These objectives could be attained by a state agency with transit properties under its jurisdiction and then extended to agencies in other states. The key is uniform data among agencies.

CONCLUSIONS

This paper has demonstrated a practical application of a procedure for evaluating transit maintenance activities. The application to a typical property has shown an organized way to characterize the performance levels of a maintenance organization's elements. The information used and its interpretation relative to Table 1 serve as a guide to transit agencies for using the evaluation framework. The framework suggests promise for promoting comparability among maintenance departments--something that has been elusive in the study of maintenance so far. Extensions to a more objective method appear possible if the framework presented here is refined to provide numerical scores and quantified relationships with performance. Approaches to this end have been provided and should be tested.

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