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Potential for Use of Natural Brines in Highway Applications

WILLIAM A. SACK and RONALD W. ECK

ABSTRACT

Large quantities of strong salt brines are often produced as by-products during extraction of oil and gas. The potential use of waste brines as replacements for conventional sodium and calcium chlorides in highway deicing and in dust control and stabilization was evaluated in laboratory testing. From various geologic formations and depths of the central Appalachian region, 49 samples of brine were collected and analyzed to establish brine quality and variability and to examine potential environmental problems. Analytical testing was carried out for general parameters such as total dissolved solids, pH, and conductivity and for major, minor, and trace constituents. Major constituents of Appalachian brines were chlorides, sodium, calcium, magnesium, and potassium. A variety of minor and trace constituents were noted in the brines, including iron, sulfate, barium, cadmium, chromium, lead, and ammonia. In most cases, concentrations of the minor constituents were not significant; however, certain formations in a given geographical area were found to contain elevated levels of certain components. Brines from different formations had significantly different concentrations of minor and trace constituents. Stability tests showed that brines will not form crystals in closed storage tanks. The constituents of the natural brines were compared with those of conventional deicing agents. The brines were generally higher in iron, zinc, and barium, whereas the conventional chemicals were higher in chrome and cadmium. It was concluded that there are significant quantities of natural brines from the central Appalachian region that are suitable for highway applications.

Sodium and calcium chlorides have been widely used in highway applications because of their low cost, ease of application, and solubility in water. The two principal uses of these salts have been winter deicing and road stabilization and dust control.

The chlorides are useful in winter maintenance because they melt snow as it falls, melt the compacted snow that remains after plowing, weaken the bond between the snow and ice and the road surface, and prevent the formation of ice films. Sodium chloride is more commonly used in deicing applications because of its lower cost (1, pp. 580-612). The primary advantage of calcium chloride is that it melts ice at lower temperatures than does sodium chloride (calcium chloride has a eutectic temperature of -58° F versus -6° F for sodium chloride).

Sodium and calcium chlorides are frequently used as surface treatments on unpaved roads. Because they keep unpaved surfaces moist, the chlorides virtually eliminate the nuisances and hazards associated with dust. By controlling dust, the fine materials that provide binding are kept in place and surfaces remain consolidated. Consolidated surfaces drain properly, resist ravelling, and remain hard and smooth. Calcium chloride is particularly attractive as a dust control and stabilization agent because it readily attracts moisture from the air and other sources.

In recent years, the costs of sodium and calcium chlorides have increased dramatically. The impacts of this trend have been most significant in winter maintenance; providing a bare pavement has placed a serious financial strain on many highway agencies. Under the constraints of tight operating budgets, highway agencies are seeking ways to minimize the use of chloride chemicals and alternative materials to substitute for the conventional agents.

One approach is to use liquid chloride chemicals (2). A number of agencies prewet deicing salts with liquids for faster action and reduction of losses due to salt bounce-off. Some agencies apply liquid brine directly to the roadway. A smaller number of agencies mix liquids and abrasives to freezeproof stockpiles and to provide some melting action when air temperatures increase. There are also several examples of agencies that use liquid chemicals for soil stabilization and dust control (3,4). The brines that have been used in all of these applications could be classified as either commercial chemicals or natural brines that are often produced during extraction of oil and gas.

Because natural brines are generated in significant quantities in several regions of the country as an unwanted by-product of oil and gas production, it appears appropriate to examine the use of such brines in highway applications. Brines are often much more concentrated than seawater. Thus, they are difficult to dispose of in an environmentally acceptable manner. The currently preferred method of brine disposal is via injection wells; however, in some parts of the country (for example, the Appalachian region), injection is often not feasible or very expensive because of a lack of sufficiently permeable formations. In addition, increased concern over groundwater contamination may result in legislation that prohibits or curtails deep-well injection. Because there is currently no completely satisfactory and cost-effective method of waste brine disposal, it is often discharged directly into ground or surface waters with potential deterioration of water quality.

Use of natural brine for highway purposes could solve several problems simultaneously. The oil and gas industry would be able to dispose of an unwanted by-product, and highway agencies could acquire a valuable agent for deicing or stabilization or both at minimal cost. Furthermore, the natural brine that is used would be applied at controlled rates rather than discharged directly to the environment as is now frequently done.

In spite of the attractiveness of using natural brine in highway applications, there are a number of unanswered questions that must be addressed. The quantity of brine available for highway purposes in a given geographical area must be determined. Although major salts in brines are known, the relative fraction of each is expected to vary with depth and geologic formation and from region to region. Thus, the variation in brine composition as a function of geology and geography must be established, because this will play a key role in determining the utility of brine as a highway material. In addition to the major salts, brines may contain a number of minor or trace constituents, including sulfate, iodide, iron, barium, arsenic, and chromium. Chemical analyses for a number of the minor and trace constituents should be performed to assess potential water pollution problems. It will be necessary to compare the brines used as deicing agents with conventional dry salts with respect to corrosion and pavement deterioration characteristics. Similarly, comparisons are needed of the effects of brines and commercial deicing agents on melting, skid resistance, and refreezing of roadway surfaces. Problems and costs of brine transportation, storage, and handling need to be identified and compared with those for conventional chemicals for both deicing and stabilization applications.

OBJECTIVES

A comprehensive research project was conducted at West Virginia University to address the questions raised in the foregoing discussion. The study methodology included both laboratory and field-testing programs. This paper presents the results of laboratory testing conducted to achieve the following objectives:

- To test properties and variability of brines from several West Virginia oil and gas fields to establish chemical composition in relation to the feasibility of using brines for highway applications and for potential environmental problems,
- To compare the constituents of West Virginia oil and gas field brines with conventional deicing and stabilization chemicals, and
- To examine the freezing and stability characteristics of West Virginia brines.

The quantity of brine available for highway purposes in West Virginia is also discussed. The other aspects of the project, addressing related questions about the overall feasibility of natural brines as a highway material, have been described in previous papers (5,6). Although the main focus of the paper is on the quality and quantity of brines in West Virginia, the results are believed to be directly applicable to other eastern brine-producing states such as Pennsylvania, Ohio, and New York (7,pp.294-321). Investigation into the use of eastern brines for dust palliative and stabilization purposes was beyond the scope of this study, but on the basis of recent studies (8,9), this is an area in which additional research appears promising.

FIELD-SAMPLING PROGRAM

Brines were sampled from oil and gas fields in the northern and central portion of West Virginia. Fields were selected so as to obtain brines from a number of different geological formations and depths. The project work plan specified that at least five fields were to be tested; five samples were to be taken from each field over a period of time.

In order to gain information on brine production and availability, contacts were made with several state agencies involved in oil and gas production, various oil and gas companies, and several oil and gas industry trade associations. The oil and gas industry was extremely supportive of the work; five companies provided brine samples or quantities of brine or both. Choice of fields to be sampled was made largely on the basis of recommendations of the oil and gas producers, because they were the most knowledgeable as to where brine production occurs.

Forty-nine samples were collected over a 17-month period from September 1981 to January 1983. Samples were obtained from 12 separate oil and gas fields as designated by Cardwell and Avary (10). Brines were sampled from 13 counties.

Samples were collected from 8 different geological formations, which included more than 12 different oil and gas zones as noted in Table 1. The formations ranged from the Upper Mississipian to the Lower Silurian. Depths of wells from which samples were taken ranged from 1,980 to 11,380 ft.

TABLE 1 Geological Formation, Zone, and Depth of Brines Sampled

Formation	Zone	No. of Samples	Range of Depth (ft)
Mauch Chunk	Maxon	1	1,980
Greenbrier	Big Injun, Big Lime	4	2,050-2,500
Pocono	Weir, Berea	7	2,300-3,000
Hampshire	Gantz, Fourth, Fifth	12	2,380-4,000
Chemung	Benson, Speechley, Riley, Balltown	8	3,825-4,575
Huntersville Chert	Not available	7	7,450-7,900
Oriskany	Not available	9	5,110-8,270
Tuscarora	Not available	1	11,380

BRINE QUALITY CONSIDERATIONS

In the analysis of the composition of the 49 brines collected in this study, 20 different types of tests were performed. Not all of the tests were carried out for each brine sample because of time and resource constraints.

The range and average value for each test parameter are given in Table 2. Although average values are presented in each case, the average concentration is not believed to be very meaningful for parameters such as barium where variations in levels between brines from different formations are very large. Table 2 also presents a range of values reported for brines in West Virginia, Pennsylvania, and Ohio. Note that the range given is not meant to be comprehensive but represents a sampling of brines with total dissolved solids (TDS) greater than 80 000 mg/L, which was judged to be typical of brines produced in the three states. The constituents determined were divided into four main groups:

1. General parameters: TDS, conductivity, density, pH, acidity;
2. Major constituents: chloride, sodium, calcium, magnesium, and potassium;
3. Minor constituents: iron, sulfate, barium, ammonia, and total organic carbon (TOC); and
4. Trace constituents: zinc, cadmium, arsenic, lead, and chromium.

TABLE 2 Comparison of Project Brine Concentration with Reported Values (11,13,15)

	Project Brines		
Item	Range	Mean	Reported Range[a]
Conductivity (μmohs/cm)	200 000-605 000	413 800	140 000-598 000
Density (lb/gal)	9.191-10.129	9.774	8.985-10.235
pH	2.72-6.14	4.3	4.4-6.5
Acidity (mg/L)	80-227	144	2-560
Concentration (mg/L)			
TDS	90 420-323 700	218 600	80 000-373 000
Cl	57 510-192 420	128 600	52 500-190 840
Na	29 130-82 240	52 740	37 150-75 000
Ca	5470-57 900	31 310	8790-49 000
Mg	645-4950	3200	1900-10 000
K	30-3310	590	122-8200
Fe	28-750	276	2-560
SO_4	<5-547	163	0-1100
Ba	1.3-2500	545	0-1150
NH_3-N	11-386	51	7-450
TOC	6-45	29	NA
Cd	<0.01-1.627	0.365	<0.1-6.0
Cr	<0.06	<0.06	<0.1-0.7
As	0.138-0.457	0.263	NA
Pb	1.583-6.100	3.360	<0.1-6.0
Zn	0.212-1.739	0.619	0-13

Note: NA = not available; TDS = total dissolved solids; TOC = total organic carbon.
[a]West Virginia, Ohio, and Pennsylvania.

General Parameters and Major Constituents

The TDS of the samples collected ranged from 90 420 to 323 700 mg/L with a mean value of 218 600 mg/L (Table 2). This TDS range is typical of that found in surrounding states. Brine strength generally increased with depth. This relationship has also been reported by others, including Waite et al. (11), Hoskins (12), and Poth (13). Exceptions to this general observation are probably due to dilution by fresh water as noted by Poth (13).

The levels of the so-called major constituents (Cl, Na, Ca, Mg, and K) are noted in Table 2. It may be seen that the average calcium concentration was more than 31 000 mg/L. This is significant in that the presence of calcium salts is known to allow the use of deicing agents at lower temperatures than is feasible with sodium salts alone. A high calcium level is also desirable for use in dust palliative applications. As shown in Table 2, concentrations of the major constituents in the brines sampled fall within the ranges reported by others.

The data were analyzed to examine the potential relationship between TDS and the major constituents, including conductivity. A statistical package was used to plot the data, perform a linear regression, calculate the correlation coefficient, and determine coefficients for the equation of the line of best fit. Correlation coefficients were found to be .989 and .966 for chloride and sodium, respectively, which indicated relatively good correlation between TDS and these two parameters. Good correlation was noted between TDS and conductivity; the correlation coefficient was .933. However, the respective correlation coefficients for calcium, magnesium, and potassium were .754, .365, and .613, which indicated data scatter and poor correlation. Similar results were found by Poth (13) for Pennsylvania brines.

Minor and Trace Constituents

Iron, sulfate, barium, ammonia, and TOC are categorized in this paper as minor constituents, although the classification is admittedly somewhat arbitrary. Iron ranged from 28 to 750 mg/L with an average value of 276 mg/L, as noted in Table 2. The high variability of iron in brines is probably mainly attributable to sample handling during collection and analysis. On exposure to air, ferrous iron will slowly oxidize to ferric iron at the pH values normally prevailing in brines. The ferric iron may settle as an insoluble precipitate in the bottom of brine storage tanks or pits or even in a sample bottle and therefore escape analysis.

Sulfate levels, which varied from 5 to 547 mg/L (average 163 mg/L), are of interest with respect to attack of concrete. Pierce (14) concluded that sulfate levels of 150 mg/L or less would result in negligible attack on concrete, whereas levels of 150 to 1500 mg/L would show a positive degree of attack and above 1500 mg/L, the degree of attack would be severe. Also to be considered is that brine applied to the roadway would be diluted by snow or ice almost immediately and would run off as melting occurred. Based on the foregoing considerations, the sulfate level in West Virginia brines would not be expected to contribute significantly to concrete deterioration. Sulfate would be expected to be low in brines containing elevated concentrations of barium because barium sulfate (barite) has a solubility of only around 3 mg/L at 64.4° F. This was borne out in project samples that had high barium levels in that low sulfates were typically found there. It may be seen that barium levels varied widely in the brines sampled; the range was from 1.3 to 2500 mg/L. Barium levels over 25 mg/L occurred in 22 of the 48 samples analyzed for barium. However, almost all of the high-barium samples were taken from one field where brine was produced from the Huntersville Chert and Oriskany formations. Other investigators have also reported the presence of elevated barium levels in Huntersville Chert and Big Injun brines (15).

Ammonia and TOC levels were also examined for a limited number of samples. The level of ammonia ranged from 11 to 386 mg/L and TOC varied from 6 to 45 mg/L. These levels are not likely to result in environmental problems when brine is used for deicing. A thin layer of oil was observed floating on the brine in some storage tanks. If the oil is collected along with the brine, elevated TOC values and possible slippery pavement conditions could result. When the brines are removed from storage tanks, at the wellhead it is relatively easy to avoid oil contamination simply by leaving the last foot of liquid in the brine storage tank.

Five trace constituents were analyzed: arsenic, cadmium, lead, zinc, and chromium as noted in Table 2. The values are generally in the range found by others for brines in this area. All of the trace constituents except zinc have maximum limits based on toxicity under the Resource Conservation and Recovery Act (RCRA) of 1976. It is important to note that production brines are excluded from regulation under RCRA and that the following comparison with RCRA-regulated wastes is made simply to gain a perspective on the trace constituent levels. Table 3 presents the RCRA limits and range of sample values obtained for the trace constituents and for barium, which is also covered by RCRA. Also shown in Table 3 is the number of times the RCRA limits were exceeded by the 49 project brine samples. It may be noted that barium is probably the only element of concern and, as noted earlier, most of the high-barium samples originated from one oil and gas field. Brines from formations with high barium levels would require pretreatment for reduction of the element before highway application.

Brine Variability

One of the objectives of the brine-sampling program was to evaluate variability in quality from dif-

TABLE 3 Comparison of Trace Constituent Values with RCRA Limits

Constituent	Maximum Limit Under RCRA (mg/L)	Range of Project Brines (mg/L)	No. of Samples Exceeding Limit
Arsenic	5	0.138-0.457	0
Barium	100	1.3-2500	22
Cadmium	1	<0.01-1.627	2
Chromium	5	<0.06	0
Lead	5	1.583-6.100	2

ferent formations and zones as well as changes in brine quality over a period of time for a given formation. Another aspect of brine variability of interest is the change in brine quality from location to location for a given formation or zone.

Nine different sample groupings were made in order to evaluate variability. Groupings were established based on the number of formations, zones, counties, or wells from which the samples were taken. Sampling extended over a time span of approximately 17 months. For each grouping of samples, variation was determined for each of the sample parameters by using the coefficient of variation (standard deviation divided by mean).

Table 4 presents the percent coefficient of variation (percent CV) for all groups for 10 sample constituents. The average percent CV for each group is also listed. Examination of Table 4 reveals that the largest variation occurs in Group 2A, which includes samples from two formations, four zones, and two counties. Sampling from different counties does not necessarily produce large variability, however, as may be noted from groups 1A (four counties) and 3A (six counties). Therefore, major variations in brine quality were not due to areal differences but to formation and zone-quality differences. The CV for the TDS of samples from Group 1A was only 5.6 percent even though 13 different wells were sampled, which indicates relatively uniform strength of the brines from four counties and two deep-lying formations. Samples taken from single wells (1C, 2C, 2D, 3B) generally exhibited the lowest variation, as would be expected. For example, the percent CV for TDS was only 3 percent for Group 2C. The seven samples in this group were taken over a period of 13 months and analysis of the data showed no trend in increasing or decreasing concentration with time.

The variation of brine quality between four different formations is demonstrated by the data in Table 5, where mean values are shown for a variety of brine quality parameters. Comparison of values clearly illustrates that brines from different formations have markedly different concentrations of major and trace constituents, as would be expected. Brines sampled from the deeper-lying Huntersville Chert and Oriskany formations were almost twice as strong as those from the Chemung and Pocono formations. It is interesting to note that the Chemung and Pocono samples are weaker than those from the Hampshire formation, which actually lies between them.

Comparison of Constituents in Dry Deicing Agents and Brines

It would be expected that the dry agents (NaCl and $CaCl_2$) used for deicing or road stabilization would also contain a variety of minor and trace constituents, although little published information is available in this regard. Seven dry agents were analyzed for six minor and trace substances, as shown in Table 6. The samples, both sodium chlorides, were randomly collected over a 2-year period from three sources: West Virginia Department of Highways (WVDOH) Sabraton maintenance facility, West Virginia University (WVU) physical plant, and the city of Morgantown. In order to compare the dry agents with the brines, the dry salts were first dissolved in distilled water to approximately 200 000 mg/L and the TDS of each sample was determined. Results were then expressed as milligrams of constituent per kilogram TDS, which allows direct comparison of the dry agents and the brines. Also shown in Table 6 are results adapted from an analysis (11) of dry NaCl used in Pennsylvania. The brine group values presented are group average values for each constituent. The samples in the groups shown represent every major formation sampled.

Examination of the data in Table 6 shows that the dry agents as well as the brines contain a variety of trace constituents. The brines are generally higher in iron, zinc, and barium, whereas the dry agents are higher in chrome and cadmium. The dry calcium chloride samples also had elevated lead levels when compared with the brines. However, because relatively little calcium salt is used at present for deicing, the higher lead values do not appear significant.

TABLE 4 Variability of Brine Samples Within Groups

Item	Group 1A	1B	1C	2A	2B	2C	2D	3A	3B
No. of samples	16	8	3	18	10	7	3	10	5
No. of formations	2	2	1	2	1	1	1	1	1
No. of counties	4	1	1	2	2	1	1	6	1
No. of zones	1	1	1	4	3	1	1	3	1
No. of wells	13	6	1	8	7	1	1	6	1
Percent CV									
TDS	5.6	2.8	0.5	9.5	5.4	3.0	1.0	22.2	1.3
Cl	3.4	1.7	1.0	10.7	5.3	1.1	1.0	18.9	1.7
Na	6.8	5.3	2.8	13.5	4.5	1.7	1.7	22.5	4.4
Ca	24.1	20.1	24.4	25.0	14.0	1.8	3.0	40.1	23.8
Mg	21.8	16.3	10.5	15.5	16.7	1.7	6.4	28.5	2.4
K	85.6	75.9	5.1	77.6	96.5	65.8	49.7	99.8	103.1
Ba	45.2	14.6	11.6	258.0	178.9	26.9	7.8	123.4	53.8
As	11.6	11.6	1.8	10.3	13.4	1.9	15.9	24.3	4.8
Pb	14.2	16.3	5.7	28.9	27.7	15.7	26.8	24.1	20.1
Zn	43.3	44.1	5.4	18.7	11.4	6.4	9.3	17.5	3.2
Avg	26.2	20.9	6.9	46.8	37.4	12.6	12.3	42.1	21.9

Note: CV = coefficient of variation; TDS = total dissolved solids. Groups are defined as follows: 1A, two formations; 1B, two formations; 1C, single well; 2A, two formations; 2B, single formation; 2C, single well; 2D, single well; 3A, single formation; 3B, single well.

TABLE 5 Variation of Brine Samples Between Formations

Item	Group 1A	2B	3A	2C
Formation	Huntersville Chert, Oriskany	Chemung	Pocono	Hampshire
Concentration (mg/L)				
TDS	303 640	185 820	167 340	217 020
Sodium	74 570	45 700	40 260	58 450
Chloride	185 390	112 360	100 790	134 650
Calcium	44 580	35 310	23 840	22 940
Lead	4.429	2.887	2.610	4.055
Arsenic	0.388	0.232	0.212	0.231
Cadmium	0.328	0.117	0.296	1.033

Note: Concentrations given are mean values. Groups are defined as follows: 1A, two formations, four counties; 2B, single formation, two counties; 3A, single formation, six counties; 2C, single formation, single well.

TABLE 6 Comparison of Constituents in Dry Deicing Agents and Brines

Agent	Constituent (mg/kg TDS) Cr	Pb	Fe	Cd	Zn	Ba
Dry salts						
NaCl-WVDOH-1982	2.4	5.8	9.1	8.3	0.7	-[a]
NaCl-Mgtn-1982	1.9	5.4	10.6	8.9	0.6	-
NaCl-Mgtn-1983	-	-	-	10.4	-	132
NaCl WVDOH-1983	-	-	-	9.1	-	96
NaCl WVU-PP-1982	2.7	6.2	17.3	6.1	0.3	-
$CaCl_2$ WVDOH-1982	6.2	53.9	24.4	16.6	2.0	-
$CaCl_2$ WVU-PP-1982	8.5	46.0	27.6	18.4	2.3	-
NaCl-Penna.	0.7	8.8	12.3	1.7	0.8	0.1
Brines						
Group 1A[b]	<0.2	14.6	1350	1.1	3.4	4838
Group 2A	<0.3	17.3	1122	2.5	3.0	454
Group 2C	<0.2	18.7	783	4.8	3.2	21.7
Group 2D	<0.3	12.2	315	<0.05	2.9	50.8
Group 3B	<0.3	14.4	631	2.5	2.0	65.5

Note: WVDOH = West Virginia Department of Highways; Mgtn = Morgantown; WVU = West Virginia University; PP = physical plant.

[a]Data unavailable.
[b]See Table 4 for definition of groups.

Freezing Tests

Freezing tests were carried out on brines and dry salt solutions at temperatures of from 5 to 15.8° F. Testing was done in an environmental chamber where a fan provided continuous air circulation to maintain the constant temperature desired. Samples were covered to avoid evaporation.

Table 7 presents the test results, showing that eight different brine samples were used in four different concentration ranges. In addition, the sodium chloride deicing agents from two different sources were tested for comparison in two different concentration ranges. Temperatures of 5.0, 8.6, 10.4, 12.2, 14.0, and 15.8° F were used. The four strongest brines showed no indication of freezing even at 5° F, although some salt crystals dropped out of solution in the strongest brine because of insolubility at the lowest temperature. This would not be expected to cause a problem during storage because the crystals would redissolve as temperatures rose. The stronger NaCl solutions both had some ice crystals at 5° F even though brines 12 and 17, which were relatively lower in TDS, did not. The superior performance of the brines at 5° F was probably due to their $CaCl_2$ content. The concentration of NaCl that would just freeze at 5° F is about 214 500 mg/L (16), whereas that of $CaCl_2$ at 5° F is estimated as 196 800 mg/L (17).

At 10.4° F, none of the brines were completely frozen, although the weakest brines (10 and 16) still had ice crystals floating on top of the brine. At 14.0° F, the weakest brines and the weakest salt solutions still had some ice crystals. At 15.8° F, no ice crystals were noted even in the weakest brines.

Brine Stability

Because brines contain high concentrations of a variety of salts, there is concern that, with time, salts may precipitate or form crystals, which may interfere with brine storage and handling. Potential brine stability problems were investigated in both covered and uncovered containers. The effect of temperature and type of container (glass and unpro-

TABLE 7 Freezing-Test Results

Sample	TDS (mg/L)	Condition of Sample by Temperature (° F) 5.0	8.6	10.4	12.2	14.0	15.8
B-10	164 380	X	IC-80%	IC-30%	IC-25%	IC-25%	NF
B-16	161 460	X	IC-80%	IC-25%	IC-20%	IC-20%	NF
B-20	188 760	X	IC-50%	NF	NF	-[a]	-
B-37	190 230	X	IC-30%	NF	NF	-	-
B-12	215 420	NF	NF	NF	NF	-	-
B-17	212 160	NF	NF	NF	NF	-	-
B-32	323 700	NF	NF	NF	NF	-	-
B-14	305 180	NF	NF	NF	NF	-	-
Dry NaCl							
Morgantown	222 780	IC-10%	NF	NF	NF	-	-
WVDOH	220 950	IC-15%	NF	NF	NF	-	-
WVDOH	163 690	-	-	-	-	IC-25%	-
WVDOH	161 700	-	-	-	-	IC-30%	-

Note: X = frozen; IC = ice crystals; NF = not frozen; SC = salt crystals; B = brine.

[a]Dash indicates not tested.

tected steel) was also examined. Initial volumes of brine in the glass and steel containers were 800 and 100 ml, respectively.

Six different brines were used during the testing in closed containers. All tests were run in duplicate except those in the glass bottles. No major change (salt precipitation or crystallization) in any sample was noted either at room temperature or at 40° F for as long as 20 months of observation. In some samples, there was a small amount of iron oxide floc on the bottom in the first 1 to 5 weeks as iron in the sample oxidized and precipitated. However, the small amount of floc formed would have no impact on storage or handling of the brine. Potential concrete pavement discoloration due to the iron floc has been discussed in a previous paper (6).

Uncovered stability tests were carried out in duplicate with two different brines. Samples were allowed to evaporate until salt crystallization and precipitation occurred in all cases. Stability was examined both at room temperature and under conditions of alternating warm and cold temperatures to simulate year-round storage of brine. Estimates of the amount of evaporation were made by observing changes in sample depth for the steel containers and by observation of both depth and weight changes for the glass containers. The final TDS was estimated from the initial TDS based on the change in sample volume. Observations were made approximately every 2 days to record the onset of crystal formation or precipitation. For one brine, the sample began to form crystals after 36 percent evaporation in glass beakers and after about 55 percent evaporation in the steel containers. The stronger brine tested exhibited crystal formation after about 9.5 percent evaporation in glass and 14 percent in steel containers. It is not known why crystals were formed earlier in glass than in steel containers, but the latter would be expected to give results closer to those expected during field storage of brines if uncovered steel tanks were used. For the steel containers, it may be noted that brine became unstable over about 375 000 mg/L. This was to be expected because the maximum concentration of brine typically noted in formations (presumably near saturation) is around 350 000 mg/L.

After crystal formation was noted, distilled water was added to bring the brines back to their original test volume in order to observe whether the crystals would redissolve. In all cases, it was noted that the crystals went back into solution, which showed that the crystallization was reversible.

In summary, the stability tests showed that the brines will be stable in covered storage tanks. If uncovered tanks are used, crystals will form if brine strength is allowed to increase to around 375 000 mg/L TDS. It should be noted that very little net evaporation would occur much of the year (especially in winter) in West Virginia, even with uncovered tanks, because of normal rain and snowfall.

BRINE QUANTITY CONSIDERATIONS

The quantity of brine produced from a given well depends on a variety of factors, including the geological formation tapped and its depth and the well's location, construction, age, and operation (7). Many wells produce little brine when first put into production but produce more with time; others yield large quantities of brine initially.

The actual quantity of brine produced nationally is difficult to determine reliably because many states do not keep detailed records. A study made by the Interstate Oil Compact Commission (IOCC) (18) estimated that 23.7 million barrels of brine per day were being produced nationwide from oil production in 1963; 115,068 barrels were produced in West Virginia. It is not clear in the report whether the West Virginia figure also included brine from gas wells, but it appears that it did.

No comprehensive figures were available from West Virginia state agencies on the quantities of brine produced in the state. However, recent studies regarding brine production had been made for Ohio and Pennsylvania that may be used to estimate brine production in West Virginia. In a report prepared by Templeton and Associates (19) for the Ohio Water Development Authority, it was noted that 35,000 active oil and gas wells in Ohio produced approximately 40,000 barrels of salt water per day in 1979. As part of a study for the Pennsylvania Department of Natural Resources, Waite et al. (11) estimated typical ranges in waste fluid volume in Pennsylvania produced per well. Their results are presented in Table 8 for shallow and deep gas and oil wells.

In order to make comparisons of brine production in West Virginia based on the data from Ohio and Pennsylvania, the number of active gas and oil wells and the production for each state as reported by the IOCC (20) is presented in Table 9. It may be seen that West Virginia has somewhat greater total gas production than the other two states but that the gas production per well is similar in all three states. Ohio leads by far in total oil production and in production per well, whereas Pennsylvania and West Virginia show fairly similar oil production per well. Based on the similar oil and gas production statistics in West Virginia and Pennsylvania and on the fact that many of the same producing formations are in use in the two states, the Pennsylvania brine production values were used to estimate brine quantities for West Virginia.

Examination of Table 8 shows that, as expected, brine production is greater for deep wells than for shallow wells. In West Virginia, wells are classed as deep if they are more than 6,000 ft or are below the top of the Huntersville Chert or Onondaga Limestone formations. Based on this classification, approximately 90 percent of the gas wells and 100 percent of the oil wells in West Virginia may be designated as shallow. Using average values from Table 8 and the number of wells as given in Table 9, it was estimated that 480 million gal of brine are produced annually in West Virginia. A second estimate based on the adjusted data from the IOCC (20) noted earlier gave 1,100 million gal per year. The

TABLE 8 Estimated Waste Fluid Volumes (11)

Development Area	Waste Fluid Type	Typical Ranges in Waste Fluid Volumes per Well
Shallow oil	Fluid produced during drilling[a]	0-2,000 gal
Venango District	Stimulation fluid	26,000 gal
	Production fluid (after 6 months of pumping)	1-2 bbl/day (42-84 gal/day)
Bradford District	Fluid produced during drilling[a]	0-2,000 gal
	Stimulation fluid	30,000 gal
	Production fluid (after 6 months of pumping)	1-2 bbl/day (42-84 gal/day)
Shallow gas (Upper Devonian)	Fluid produced during drilling[a]	0-5,000 gal
	Stimulation fluid	40,000 gal
	Production fluid	0-1 bbl/day (0-42 gal/day)
Deep gas (Medina formation)	Fluid produced during drilling[a]	0-25,200 gal
	Stimulation fluid	58,800 gal
	Production fluid	2-4 bbl/day (84-168 gal/day)

Note: Estimated volumes of fluids produced during drilling, does not include top hole water or ground water encountered before surface pipe is set. All ranges are considered typical for the type of well indicated. Individual wells or groups of wells in selected locations may differ signficantly from the ranges indicated here.

[a]These estimates apply only to air-rotary-drilled holes.

TABLE 9 Oil and Gas Production Statistics for Ohio, Pennsylvania, and West Virginia, 1981 (*20*)

	Gas			Oil		
		Yield			Yield	
State	No. of Wells	Annual (ft^3 000,000s)	Per Well (ft^3 000s/day)	No. of Wells	Annual (bbl x 10^3)	Per Well (bbl/day)
West Virginia	26,925	161,251	16	14,700	2,433	0.4
Ohio	18,619	141,134	18	22,441	13,551	1.6
Pennsylvania	20,526	122,456	16	26,138	3,229	0.3

lower estimate is felt to be more reliable because it is based on more recent data. The 480 million gal of brine translates to a unit production of 1.3 gal of brine per 1,000 ft^3 of gas produced and 2.6 bbl brine per barrel of oil produced. It is important to bear in mind that brine production varies widely from well to well depending on factors discussed earlier. Thus, although an average value of 0.52 bbl of brine per day was used in estimating brine production from an average West Virginia gas well, actual values reported by oil and gas producers vary from zero to 25 bbl per day.

It is recognized that even if the previous estimate of 480 million gal of brine production per year is reasonable, only a portion of the brine would be available or suitable for highway applications. Brines unsuitable for use include those that are too weak or that contain undesirable levels of contaminants. It is also likely that the use of brine from a number of wells would not be cost-effective because of their remote location or low production or both, which would result in unacceptably high transportation costs. If only 10 percent of the estimated 480 million gal per year was available for use on roadways, the dry salt equivalent would amount to approximately 34,000 tons (assuming a TDS of 170 000 mg/L). This amount is about 35 percent of the salt used for deicing in the 1981 winter season by WVDOH.

The supply of brine available over a period of years will be an important factor in evaluating the feasibility of brine use. In this regard, it may be noted that during the past 5 years of available record (1977 to 1981), gas production in West Virginia increased approximately 6 percent and oil production remained approximately constant (20). Thus, it would appear that the quantity of brine available increased slightly in the same period.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the results of the study described here, it was concluded that there are significant quantities of natural brines from the central Appalachian region (including West Virginia, Ohio, Pennsylvania, and New York) that are suitable for highway applications. Brines from this region have relatively high calcium concentrations. This is an asset both in deicing and in stabilization and dust control. Of the minor and trace constituents in these brines, barium was the only element of concern.

Major variations in brine quality are not due to areal differences but to differences in formation and zone. Brines from different formations have significantly different concentrations of major and trace constituents. Brine strength tends to increase with depth. Over a period of 13 months, there was no change in brine concentration from a given formation. It is recommended that brines continue to be monitored over time to determine any long-term changes in composition.

Stability tests showed that the brines will be stable in covered storage tanks. If uncovered tanks are used, crystals will form if brine strength is allowed to increase to around 375 000 mg/L TDS. Under the relatively humid conditions found in the Appalachian region, little net evaporation would be expected to occur, even with uncovered tanks.

The constituents of the natural brines examined were compared with those of conventional chloride chemicals. The brines were generally higher in iron, zinc, and barium, whereas the conventional chemicals were higher in chrome and cadmium. Dry calcium chloride samples had elevated lead levels when compared with the brines.

Because of the apparent attractiveness of using natural brines in highway applications, it is recommended that studies similar to the one described here be conducted in other geographic regions that produce significant quantities of brine. Analysis of brines could identify those formations or zones that are suitable sources of brines for highway applications. Formations producing brines that are too weak for highway applications or that create environmental problems could be delineated and avoided. The analysis might also suggest instances where pretreatment of brines, if they are attainable at low cost, could produce a suitable material for highway applications.

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Calcium Magnesium Acetate Research in Washington State

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ABSTRACT

As part of a pooled-fund research project, the Washington State Department of Transportation was selected to field test approximately 100 tons of calcium magnesium acetate (CMA) to evaluate its potential as a deicing chemical in direct comparison with salt (sodium chloride) and urea. Evaluation included all aspects of storage, handling, use, and performance. CMA was applied whenever necessary at each test site; the same application rates were used as those now used for salt. Typical equipment consisted of front dump trucks with the spinner ahead of the rear axle and rear-discharge hopper trucks. All equipment was used without modification. The use of CMA at the beginning of a storm reduced the amount of bonding of snow to the roadway surface. This effect of keeping the roadway surface bare for longer periods of time reduced the cost of snow fighting. This was accomplished with a chemical application rate of 125 lb per lane mile. The addition of sand to CMA reduced the problems of dust, caking, and uneven distribution. The sand provided moisture and weight to the application, which resulted in a smoother, more even distribution. CMA spread above the ice and snow was excessively dusty, which created problems in the spreading and distribution. CMA is slower to react on compact snow and ice than is salt or urea. This delay in reaction time was not considered a handicap in the overall snow-fighting procedure. The conclusion was that CMA shows promise as a deicing-melting chemical. The problems of dust, light weight, and brittleness need further research and may be significantly alleviated by development of a hydrated compound.

The Washington State Department of Transportation field tested calcium magnesium acetate (CMA) in a wide range of weather conditions and temperatures with standard equipment.

Although slower acting than salt or urea by about 20 min, CMA does break the bond between compact snow or ice and the roadway surface. It is most effective at about 25° F, which is consistent with results for salt and urea. A mixture of CMA and sand proved to have approximately the same results as a similar salt-sand mixture. The sand helps hold the chemical on the roadway until melting action begins. When applied to roadway frost, CMA appeared to cause a steady draw of moisture, which required additional applications. By comparison, salt appeared to melt the ice and allow drying during warmer periods of the day.

The CMA tested was lightweight, which created difficulties in application. The material would blow off a full load, creating a minor visibility problem. The lack of weight also contributed to uneven distribution as the load was reduced through application. CMA would cake on the truck bed and in the spinner assembly whenever moisture interacted with the dust. The excessive dust also created problems in handling.

CMA applied at the beginning of a snowstorm provided the most dramatic results. The application of a small quantity (125 lb per lane mile) of CMA at the beginning of a moderate (1.5-in./hr) snowstorm maintained a compact-free roadway. The CMA was applied at 26° F in moderate traffic. Salt was applied to the opposite lanes at a rate 6 times that of CMA and required continuous plowing to keep the roadway free of slush. If this performance is verified through additional tests, it could greatly reduce the cost of snow and ice control.

The conclusion was that CMA shows promise as a deicing-melting chemical. The problems of dust, light weight, and brittleness need further research and may be significantly alleviated by development of a hydrated compound.

COMMENTS FROM MAINTENANCE SUPERINTENDENTS

The maintenance superintendents of the two test areas submitted the following comments about their use of CMA as an alternative deicer:

1. CMA reacted well with snow or ice at temperatures ranging from the mid-20s to 32° F.
2. CMA reacted slower than urea.
3. The chemical was dusty to handle; face masks had to be used.
4. Dusty conditions were created during applications; the spinner assembly on the trucks appeared to break the CMA up, which caused dust problems.
5. The single biggest problem was the drawing of frost in areas of previous applications, which caused continuous use of the chemical. Areas that would normally dry out during daylight hours would stay wet and ice up in late afternoon or early morning.
6. CMA did not react as fast as urea with the snow bottom, which caused excessive chemical movement by traffic.
7. It was believed that 400 to 600 lb per lane mile was not adequate to get the same results as those obtained with 400 to 600 lb of urea.
8. CMA appeared to work best when applied with sand. The sand helped hold the chemical until melting action began.
9. Temperatures below 24° F greatly reduced the melting effects of CMA.
10. No corrosive effects of CMA were noticed in any of the equipment used during the testing.
11. As a traction device, CMA noticeably prevented any ice floor from developing, although this was not the case with salt in this same storm.
12. CMA, when applied to compact snow and ice, generally stayed where contact was made, whereas salt slid off the lane surface.
13. Salt proved more effective in the dissipation of snow and ice in plow berms.

PHYSICAL SETTING OF STUDY

Tests were conducted in three separate areas in Washington State:

1. I-90 through the Cascade Mountains from the Snoqualmie Pass Summit at Milepost 52.4 to the western terminus of the Denny Creek viaduct at Milepost 50.4. Salt had never been used on the 3,300-ft-long viaduct and this area was used for test comparison with urea.
2. Another section of I-90 in the Snoqualmie Pass vicinity, Mileposts 56.3 to 57.0, was used for a side-by-side comparison with salt. CMA was applied to the westbound lanes and salt to the eastbound lanes, both with and without abrasives. (The state of Washington was influenced by a Pacific marine flow that resulted in 479 in. of snowfall in the Snoqualmie Pass area during the winter.)
3. The Spokane viaduct section of I-90, Mileposts 279.5 to 285.6, was used for a comparison of salt and CMA without abrasives under drier, colder conditions than are typical at Snoqualmie Pass.

Skid tests, evaluating both CMA and urea, were conducted at the Washington State Patrol Academy test tract on asphalt-concrete pavement and on portland cement concrete on I-5, Mileposts 111 to 112, northbound.

TESTING CONDITIONS

During the first quarter of the 1983 test period (ending March 31, 1983), the test areas received below-average snowfall, and chemical deicers were not necessary. However, conditions for the fourth quarter of the 1983 test period (October 1, 1983, through December 31, 1983) provided opportunities for testing CMA in a wide range of conditions and temperatures. Weather during this period included freezing rain, heavy wet snow, dry blowing snow, compact snow and ice, and beginning storm conditions.

The Snoqualmie Pass test area is equipped with eight surface system sensors that are capable of continuously monitoring and recording air and surface temperatures on the Denny Creek viaduct. Avalanche crews monitor and record meteorological data at Snoqualmie Pass on an around-the-clock basis. Drivers recorded the time and rate of application on each load of deicing chemicals; this information was compared with the sensor records to determine the volume of chemicals required to produce satisfactory results at various temperatures.

MATERIALS AND METHODS

A storage test was included in which CMA was stored in 200-lb quantities for each of five separate test methods: covered and uncovered in both bagged and bulk form and mixed in a ratio of 5 parts and to 1 part CMA by volume. All urea and salt storage was in bulk form in enclosed sheds.

Equipment consisted of front dump trucks with the spinner ahead of the axle and rear-discharge hopper trucks. The equipment was not modified for CMA.

Equal distribution rates by volume for salt, CMA, and urea were used. It was not deemed important to adjust the application rate of any individual chemical to achieve an equal melt rate. The specific gravity of salt is 2.17, that of urea is 1.33, and that of CMA is 0.83.

TEST PROCEDURES

The specific test areas were well defined for control and comparison. They were selected by the local maintenance superintendents for ease of access and application control without sacrifice to either the test program or the primary mission of keeping the highway open to traffic. Applications were performed whenever necessary.

Deicing chemical tests were documented as to application rates, handling techniques, problems encountered in application, air and surface temperatures, rate of penetration (visual comparison), length of melting condition, and general results. In an attempt to standardize the report and the data analysis, slightly modified versions of forms suggested by the Michigan Department of Transportation were used. These forms were reviewed and accepted by field personnel.

Storage testing was monitored on a monthly basis through September 1983, when the storage test site was inadvertently buried under a load of bulk salt.

Each test was documented by the drivers, supervisors, and an observer. The reporting sequence allowed an immediate report from the driver relating any problems in the delivery of CMA, a 15- to 30-min delay report from the supervisor as to reaction time of the chemicals, and a 1-hr delay report from the observer detailing the roadway surface condition.

Application rates varied, depending on weather conditions. At the Spokane site, application rates ranged from 125 lb per lane mile applied at the start of a dry snowfall at 26° F with very slight winds to 400 lb per lane mile on compact snow with 15-mph winds at 28° F. In the Snoqualmie Pass area, application rates varied from 200 to 750 lb per lane mile. The final test application used 15 tons of CMA and sand in the Snoqualmie Pass vicinity, mixed at a proportion of 1 to 5 by volume.

Skid testing was done with a full-scale tire according to ASTM E274-79, using water and various concentrations of CMA and urea as a lubricant at 40 mph on asphalt-concrete pavement and portland cement concrete surfaces.

RESULTS AND DISCUSSION

CMA appeared to be more hygroscopic than salt, although a crust would form, resulting in less actual leaching during storage than is typical for salt. CMA cannot be stored in the open under polyvinyl because the film deteriorates either from weather or from reaction to the acetic acid. The storage test area was inadvertently violated by a bulk shipment of salt, which terminated the long-term storage tests after 8 months. Results to the time of termination indicated that both bagged and bulk storage of CMA can be accomplished at a reasonable cost.

The mixing of CMA and sand (1 part CMA to 5 parts sand) in the preparation of stockpiles proved effective in protecting the stockpiles from freezing. The CMA-sand mixture also retained enough chemicals to work as a deicer. This mix ensures that a greater percentage of the material is applied where it is needed and stays there. It also reduces chemical and vehicle use as compared with separate applications and does not contribute to an increase in chloride damage.

CMA was generally about 20 min slower to react than either salt or urea, but it provided the same final reaction of breaking any bonding of the compact snow or ice with the pavement surface.

CMA was tested in weather conditions ranging from freezing fog to heavy snow. This included freezing rain, which dropped as rain but froze when it came in contact with the frozen roadway surface. When CMA was applied, the moisture from the rain assisted the CMA to work at a surface temperature of 19° F and break the bond between the ice and the roadway surface. The rain is assumed to have assisted this action, which occurred at a temperature below the normal range for this deicer. CMA is most effective above 25° F.

At the Spokane site application of CMA at the start of a dry snowstorm resulted in a significant decrease of compacting and far less effort in maintaining a bare pavement as compared with the use of salt during a 10-in. snowfall over a 6-hr period. Some observers independently noted that if CMA is applied at a rather low rate (under 200 lb per lane mile) at the beginning of a storm, it will be unlikely that compact snow and ice will form.

Regarding skid-testing results, CMA and urea were compared by using formulations similar to the Pennsylvania Transportation Institute (PTI) tests. PTI concluded that saturated solutions of CMA did not lower the friction numbers but that urea did lower the skid numbers substantially. The 2-year Washington State field experience with urea did not agree with the PTI report, and skid test results agreed with field experience. Only the first test of urea showed any significant decrease in the friction number when compared with the friction numbers using water. All the other tests showed some slight differences but each was within the limits of test reproducibility for skid numbers. Washington State laboratory personnel and personnel from PTI were unable to determine why different results occurred with duplicate procedures.

Any movement (handling, breaking bags, loading trucks, and spreading) of CMA created excessive dust. Crews had to wear masks during manual handling operations. Bulk delivery and loading would significantly reduce this problem. Dust resulting from application of CMA to the roadway through the spinner may constitute a hazard to passing vehicles because of decreased visibility in some wind conditions. Roadway dust was significantly reduced by mixing CMA and sand together in the same load.

Winds in the mountain pass sometimes blew the CMA off the roadway surface before any melting action could occur. An application of sand immediately following the CMA application provided a partial remedy to this problem. Also because of its light weight, CMA blows off the load in transport. When the load gets low, CMA does not flow smoothly through the flight chain. This results in an uneven distribution toward the end of a load. Minor modifications to the chain would probably take care of this problem if a more dense form of CMA cannot be developed.

CMA tended to cake on the dump truck bodies and in the chute and spinner assemblies. This was especially true on wet equipment or if a partial load of CMA was left in a truck after a run. Cleaning the trucks was difficult; the material had to be chipped off. Using the entire truckload each time generally eliminated clogging problems.

Maintenance crews occasionally used CMA in areas other than the designated test sites when a chemical deicer was required. This usage accelerated the crews' awareness of the effects of CMA under various conditions and indicated their acceptance of CMA as an alternative deicer.

In conclusion, CMA shows promise as a workable deicing or melting chemical. The extra cost and effort are believed to be justified in view of the high costs of corrosive damage done by salt to bridge decks and automobile bodies. The current problems of excess dust, light weight, and brittleness are, to some extent, associated with the chemical makeup. Formulation of a hydrated compound of CMA may significantly alleviate these problems.

A synopsis of each application of CMA made during this research project is given in Table 1.

CONCLUSIONS AND RECOMMENDATIONS

Although CMA has a slower reaction time on compact snow and ice than either salt or urea, this was not found unacceptable. The overall effect of a 20-min delay in reaction was not deemed to be critical in a continuous snow-fighting operation.

A mixture of 1 part CMA and 5 parts sand, stored in the open, proved sufficient to retain deicing properties and keep the stockpile from freezing. The effects of mixtures lower than 1 part CMA to 5 parts sand should be investigated. If deicing is maintained, a 1:10 mixture would be more cost-effective. Additional research should be directed toward developing a CMA product that will be more dense and dust-free. The current product is extremely dusty, which created problems in both handling and spreading.

Future testing should pursue the application of limited amounts of CMA (125 to 200 lb per lane mile)

TABLE 1 CMA Research Project

Storm	Test	Temperature (°F)	Surface	Deicing Agent (lb/lane mile) CMA	Salt	Urea	Results	Comments
Snoqualmie Pass								
1	1	29	Compact	375	375	-	CMA slower	CMA slower to break bond than salt, created less moisture, but did break bond about 10 min later
2	1	31	Compact, blowing snow	-	-	650	Slush	Snow bottom broken and with sand provided good traction; urea still working after 9 hr
	1	29	Compact, blowing snow	750	750	750	Bottom broken	Good traction after 30 min; CMA test section at higher elevation than urea; sand and salt worked 15 min faster than either CMA or urea
2	2	29	Compact, poor traction, blowing snow	650	-	650	Good traction	Compact broken; CMA worked faster than urea, but did not maintain good traction for as long a period in snowstorm
3	1	29	Compact	625	-	625	Bottom broken in 30 min with CMA; 15 min with urea	CMA did not respond as fast as urea, but gave good traction after 30 min
4	1	29	Blowing snow, thin ice	525	-	525	After application	In 30 min urea broke bond; CMA did not allow bond to form blowing snow
5	1	26	Compact, snow and ice	375	1,800	-	-	Salt and sand cleared roadway; light weight of CMA made application rate patchy
6	1	24	Thin ice	130	-	-	CMA whipped off by traffic	Heavy traffic whipped CMA off; same effect as salt and urea
7	1	26	Freezing rain	571	-	-	CMA slower	CMA mixed with sand in truck spread evenly and gave good results; slower than salt or sand but gave good traction
7	2	28	Freezing rain	400	400	-	1 hr for reaction	Suggestion made that a lighter application may frequently be better in freezing rain (videotape)
8	2	19	Blowing snow	250	-	-	-	No compact formed; bond of snow never materialized;
8	3	24		250	-	-	-	opposite lane developed compact (no other chemical used)
9	1	30	Compact, snow	1,000	-	-	Good	CMA and sand mixture (1:5) broke bottom
10	1	31	Compact, snow	400	-	-	Good	Strip melting bottom broken
11	1	31	Wet snow	400	-	400	Fair	Slower to work than urea
12	1	31	Compact, snow and ice	1,000	1,000	-	Good	Same as salt when mixed 1:5 with sand
Spokane								
1	1	22	Dry blowing snow	222	-	-	Bad	Plugged chute on truck would not allow distribution; salt and sand applied on same area because of accidents
2	1	22	Blowing snow	200	400	-	None	CMA did not break bond in dry compact; salt applied in same area for 4 hr; trouble with distribution again
3	1	25	Compact, snow	333	333	-	30 min	Penetration to roadway surface in 30 min; problems with application from chute; less moisture evident in CMA lanes than in salt lanes
4	1	25	Compact, snow	666	666	-	Good	Pavement cleared in 1 hr (two lanes); less moisture than in salt lanes; driver thought results better than in salt lanes
5	1	26	Compact, snow	600	-	-	Good	Not much traffic, but penetration to surface in 1½ hr
6	1	27	Blowing snow	200	500	-	Fine	No compact formed on CMA lanes; crews liked salt application better because slush easily removed; however, nothing formed on CMA lanes; therefore, no plowing was required
7	1	30	Black ice	125	-	-	30 min	Remove black ice in 30 min
8	1	30	Ice	416	500	-	Good	Same results as salt, no differences noted; moisture on road from previous snow was freezing; both CMA and salt broke surface bond satisfactorily
9	1	32	Wet snow				Bad	CMA plugged equipment
10	1	14	Dry snow	200	-	-	None	No results; test for lower limits; 14° F below limit of CMA, urea, and salt
11	1	23	Dry snow	400	400	-	Slower	CMA blowing off roadway and trapping snow at sides of lanes

Note: Total chemical used as follows: Snoqualmie Pass–salt, 400 tons (freezing rain, eight storms required bulk of this); urea, 200 tons (Denny Creek Bridge and selected spots); CMA, 60 tons (test area and selected spot use); Spokane–salt, 230 tons; urea, 15 tons; CMA, 38 tons (used in test versus salt).

at the onset of a snowstorm in areas where sand is undesirable. The savings to be realized from decreased plowing, sanding, and sand cleanup would influence overall costs and might significantly narrow the breakeven point between the cost of CMA and salt.

ACKNOWLEDGMENTS

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Staffing of Maintenance Crews During Winter Months

MARTIN C. RISSEL and DOUGLAS G. SCOTT

ABSTRACT

The Pennsylvania Department of Transportation wished to learn whether winter maintenance manpower was being used effectively and developed a research project for this purpose. The objectives of the study were to determine the cost-effectiveness of single- and dual-shift staffing during the winter months, identify maintenance activities that are not snow related and that can be performed during cold weather, estimate the amounts of work that can be accomplished with single and dual shifts, and ascertain optimum winter staffing patterns. Data from actual winters were obtained and computer models were developed to permit the calculation of regular time, premium time, and regular time when there was insufficient light to work and it was not snowing. Other states with weather similar to Pennsylvania's were contacted and furnished information about their use of maintenance manpower during the winter months. In-depth interviews were also conducted with Pennsylvania Department of Transportation personnel at various levels. A winter severity index based on total meteorological data rather than snowfall only was developed during this study to provide a means of approximating the relative severity of winters in terms of labor costs. The computer model permitted the cost-effectiveness of a wide variety of staffing patterns to be evaluated in each county in Pennsylvania. It was determined that dual-shift operation for at least part of the winter season can be more economical than single-shift operation in some districts and counties in Pennsylvania.

A major problem facing every state highway agency in the snow belt is to make winter maintenance operations as cost-effective as possible. On the one hand, safe winter driving conditions must be provided to the public and on the other, expenditures must be kept to a minimum because winter maintenance operations do not provide any lasting improvement to the highway system and can even contribute to its deterioration. The core of the problem usually concerns manpower because labor represents the largest class of expenditure in highway maintenance activities.

A variety of personnel assignment and allocation techniques have been used in an effort to hold labor costs down and to use manpower as effectively as possible. These include

- Same working hours as in summer with overtime as necessary,
- Reduced regular hours to compensate for increased premium time,
- Dual shifts based on storm conditions with reversion to single shifts at the end of the storm, and

• Dual shifts for the entire winter season or the portion of the season when most severe storms are expected.

The Pennsylvania Department of Transportation (PennDOT) has used the seasonal dual-shift technique for a number of years for all but 2 of its 11 districts. The beginning and ending dates of the dual shifts vary depending on the area of the state. The hours of dual shifting also vary somewhat, although the most common hours are from 4:00 a.m. to 12 noon for the first shift and from 12:00 noon to 8:00 p.m. for the second shift. Assignment of personnel to the shifts may also vary, but each shift is usually about the same size.

Increasing highway-related costs have caused PennDOT to embark on a number of research projects. In the case of winter maintenance manpower, the department wished to ascertain whether manpower was being used effectively and developed a research project with several clearly identifiable objectives. These objectives were to determine the cost-effectiveness of single- and dual-shift staffing during the winter months, identify maintenance activities that are not snow related and that can be performed during cold weather, estimate the amounts of work that can be accomplished with single and dual shifts, and ascertain optimum winter staffing patterns.

RESEARCH APPROACH

The project objectives could not be achieved satisfactorily until extensive research data had been collected and analyzed. Several methods were used in the collection of these data; they included interviews, questionnaires, statistical analysis, and inspection of department records.

Each assistant district engineer for maintenance and several county maintenance managers were interviewed. During the interview process, it was discovered that there were a number of arrangements for winter shifts. Single shifts, dual shifts, transition periods, skeleton crews, and so on, are all ways in which winter maintenance activities are now being accomplished. These various staffing schedules were examined in terms of efficiency and productivity.

The collection of weather data from the National Oceanic and Atmospheric Administration (NOAA) weather library in Silver Spring, Maryland, was one of the tasks undertaken in this project. With input from the district engineers, three representative weather stations were chosen in each district. Detailed weather data were then gathered for that location for three types of winter: those with light snowfall, average snowfall, and heavy snowfall. Types of winter were selected by recording the amount of snowfall and the number of degree-days for every winter from 1968 to 1980 at the seven National Summary Weather Stations throughout the state. The mean amount of snowfall and the standard deviation were calculated. The average winter was selected as the one having the amount of snowfall closest to the mean. The light winter was selected as the one having the amount of snowfall closest to the mean less one standard deviation. The heavy winter was selected as the one having the amount of snowfall closest to the mean plus one standard deviation.

A detailed weather data form was developed on which the following information was recorded:

- District;
- Representative weather station;
- Winter;
- Month;
- Type of winter;
- Day and date;
- Source weather station for snow, temperatures, and precipitation times;
- Inches of snow;
- Temperature; and
- Beginning and ending precipitation times.

Once this information had been collected, the detailed weather data forms were reviewed and certain inconsistencies were noted. Possible reasons for these inconsistencies were misunderstandings about reporting procedures, actual errors in reporting data, improper recording of information, and so on. Whatever the reasons for the errors, editing was required in order to make the data uniform and meaningful. To avoid bias in the editing, statistically valid procedures were used.

A series of computer programs were written to refine the weather data and calculate hours of work required for winter maintenance. These were as follows:

- Modified Weather Program (MODWP) accounts for instances in which precipitation is shown at below-freezing temperatures during the time period recorded but no snow amount is shown. This is done by defining time of ice storms.
- Storm Clearing Program (STCLP) allows time for clearing of the roadway following a storm.
- Daylight Work Program (DAYWP) determines, at various locations in the state for each day, the time of the day when there is sufficient light to work on site in the mornings and in the evenings.
- Crew Time Program (CRTMP) provides regular work hours, time during morning and evening when it is too dark to work and is not snowing, and premium time required for winter operations.

It was believed that data concerning other states' practices for working during the dark early morning and early evening hours of winter would also contribute significantly to the research data for this project. An appropriate questionnaire was prepared, which was sent to the maintenance directors in 23 states. The states with weather patterns similar to Pennsylvania's and thus thought most likely to furnish useful information were selected. Completed questionnaires were received from each of the 23 states contacted.

RESULTS

Research and analysis were completed on several major topics. These topics included

- Weather patterns,
- Weather severity index,
- Correlation of 1981-1982 computer analysis with actual data,
- Accident analysis,
- Staffing patterns,
- Work analysis (single- compared with dual-shift counties), and
- Description of crew time programs.

Weather Patterns

Cyclonic storms, the familiar low-pressure-pattern storms, are the source of most of the snow and ice conditions with which this analysis is concerned. The storm's intensity is determined by temperature, wind velocity, and precipitation. The real extent of the storm (usually 500 to 1,000 miles in diameter) and the track of the storm determine the region affected as the general pattern moves in relation to the region.

The topography of Pennsylvania--valleys, ridges, plateaus, and mountains--and the orientation of these features add complexity to the weather pattern by producing many local effects, but storm tracks usually follow one or two broad paths west or east of the mountains that bisect the state in a general southwest to northeast direction. The jet stream meanders to the east and west as well as to the north and south, and these meanderings in combination with the effects of the mountain ranges tend to determine the storm tracks because the jet stream steers the storm and the mountains tend to block it.

Storms are air in motion, so the impeding of storm movement by mountains would be expected, but there are other less obvious factors. Topography, that is, the relative elevations of the earth's surface, produces distinct effects as storms proceed over higher elevations or move from higher to lower elevations. Lowlands or bowls frequently experience significantly different weather than adjacent or surrounding areas because of the effect of topography. Topography appears to modify the weather in the central mountain region by reducing the total or the frequency of significant snowfall in winter.

Cold air, if it remains over any lake long enough in transit, can become nearly saturated. On reaching shore, the air is lifted up the hills that surround the lake, particularly to the southeast, and cooling causes condensation and precipitation in the form of snow. Under some conditions, large cumulus clouds form because the air is warmed enough over the lake to create large-scale convection and significant snowfall will occur. Added to the topographic effects in cyclonic storms, this set of conditions provides the area of extreme northwest Pennsylvania with some of the largest and most frequent snowfall.

A general topographical classification of areas in Pennsylvania by winter weather severity in terms of snow and ice (in descending order) is as follows: upslopes, uplands, plains, or bowls. A generalized map of these areas is shown in Figure 1.

Weather Severity Index

Completely objective criteria for determining the severity of a particular winter are difficult to establish because of the interaction of weather elements: temperature, precipitation, wind, solar insolation, and so on. Before the CRTMP was completed, a subjective method of evaluating the severity of a given winter was established by using only the total amount of snowfall. Winters were selected as light, average, or heavy based on relative total winter snowfall amounts.

On completion of the CRTMP, it was noted that the relative amounts of premium time that were incurred in these winters did not correspond to the winter classification. As every engineer responsible for winter maintenance operations in the snow belt instinctively realizes, the depth of snow that has fallen during any one winter may not indicate the severity of that winter in terms of expenditures. As a result, the concept of a winter severity index (SI) based on total meteorological data was developed. The information required was obtained by using the programs written for this project.

The SI developed from this data is

$$SI = S + 2M + H + T - (C/2) + R \quad (1)$$

where

- S = total inches of snowfall in the period,
- M = number of days with snowfall of 1 to 6 in.,
- H = number of days with snowfall greater than 6 in.,
- T = number of days with a maximum temperature above 32° F and a minimum temperature below 32° F,
- C = number of days with temperatures below 32° F, and
- R = total hours in the period when snow or ice occurs.

The total single-shift premium hours and the SI for the full winter period (November 1 to March 31 + 1) for each representative weather station were computed and tabulated. These values were for the same stations and period. Figure 2 shows the plot along with the result of a linear regression analysis. The correlation coefficient is .94, which indicates a high degree of correlation between SI and the CRTMP results. The equation of the linear fit curve is Y = -37.9 + .8X.

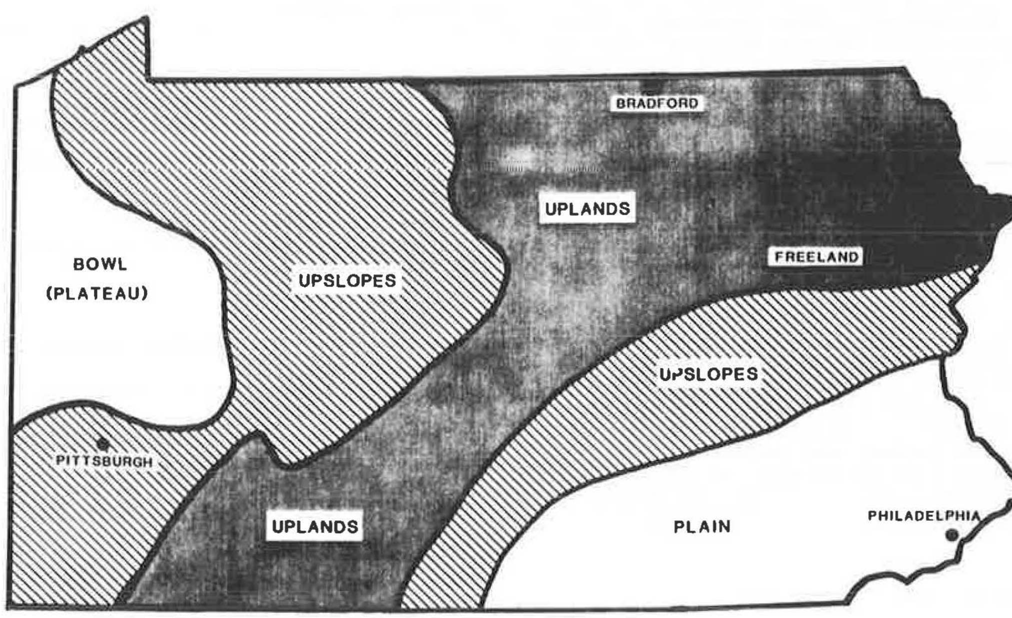

FIGURE 1 General topographical classifications of areas in Pennsylvania.

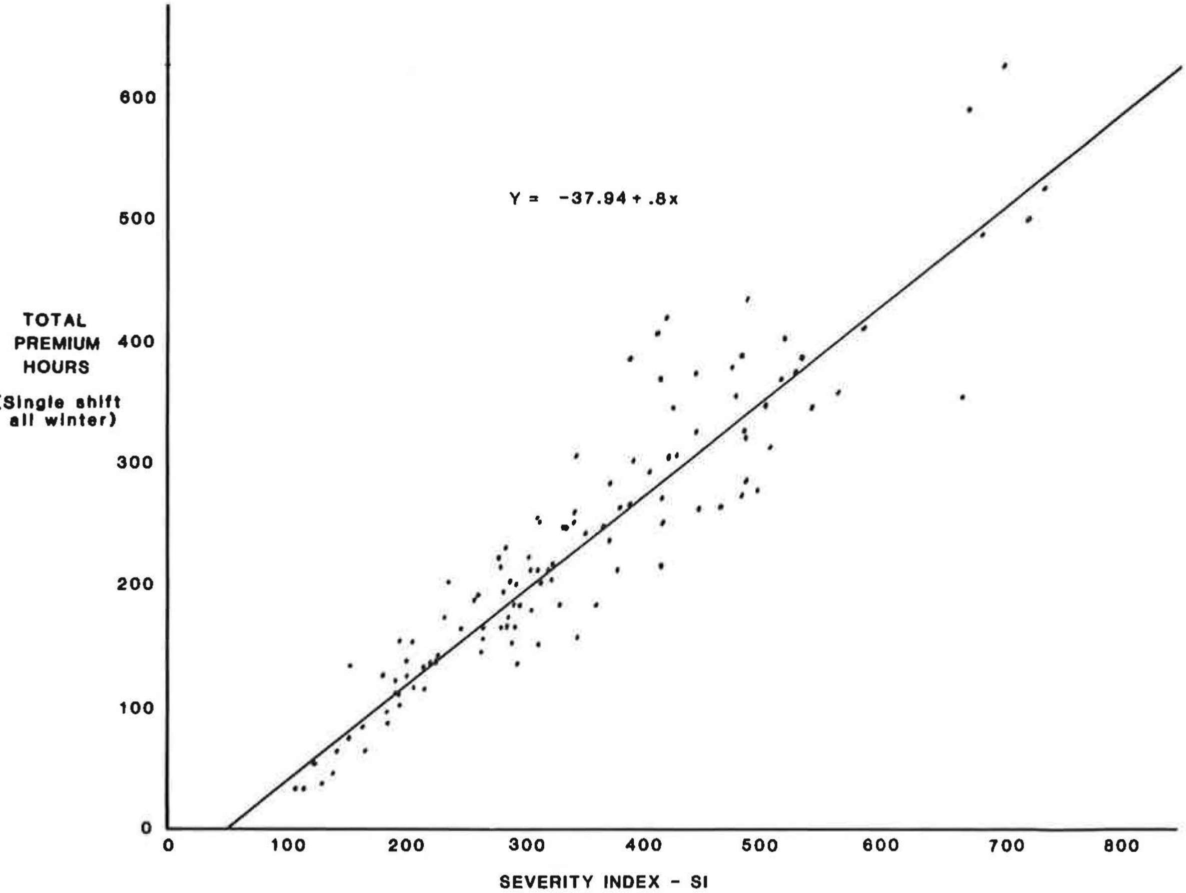

FIGURE 2 Severity index.

In the section of this paper on correlation of the 1981-1982 computer analysis with actual data, it was established that the CRTMP results showed a reasonable correspondence with actual data. The correlation of the SI with the analysis program results indicates that the SI provides a valid indicator of premium-time requirements.

The SI for any winter can be calculated, and with the linear relationship in Figure 2, a corresponding estimate of premium hours can be determined. To develop Figure 2, the SI was computed for the whole winter period and the premium hours were correlated for the same period. The same technique can be used to evaluate a portion of the winter to achieve a similar correlation. This might be useful in identifying and correlating the more severe midwinter period.

The components of the SI were then examined to determine whether the index could be further refined. This examination showed that the total hours of snow or ice in the period is the most significant component. Some components such as total snowfall for the winter had a lesser effect on the index. However, the correlation was not as good when the total hours of ice and snow alone was used as an index. It is believed that a much more extensive statistical analysis might refine the SI, because it was developed empirically.

Correlation of 1981-1982 Computer Analysis with Actual Data

The actual or reported regular and overtime hours charged to highway maintenance in the winter period between November 1, 1981 and April 11, 1982, for each county were made available to permit a comparison with the results of the CRTMP. The 1981-1982 weather for this same period was used as a data base.

A representative weather station for each county was selected on the basis of information provided by the county maintenance managers and a subjective evaluation based on weather patterns and topography. A computer analysis of 1981-1982 weather data was made for each county with weather analysis parameters held fixed and shifting periods varied to coincide with the district and county managers' stated practices. The fixed weather analysis parameters were an ice temperature of 28° F, icing times of 8:00 a.m. and 8:00 p.m., light storm with less than 4 in. of snow, and heavy storm with 4 in. or more of snow. The storm clearing times were held fixed at 2 hr for light storms and 3 hr for heavy storms on the basis of information provided by district managers. The shifts were adjusted for single- and dual-shift periods, and shift times actually used were obtained from the maintenance managers. The small difference in the length of time represented by weather records and work activity records, sick leave time, vacation time, and other factors that might cause some predictable disparity between results obtained from the CRTMP and actual records were considered and appropriate adjustments made.

The CRTMP output provided a total of regular crew hours and overtime crew hours for each shift period. Crew time was chosen to be the factor developed rather than individual time, which is too awkward and lends nothing to accuracy. For comparisons with the 1981-1982 records, however, crew time had to be converted to individual time because the department records are kept on that basis. The total regular work hours and total overtime hours for each shift period, and in turn for the entire winter period (November 1 to March 31), were computed for each county on the basis of the number of employees per shift for regular work hours and overtime hours, respectively. The total personnel assigned to overtime shifts in the county corresponds to the number of trucks plus the number of crews unless some additional information indicated otherwise. This implies only one operator for each truck plus a foreman for each crew in the normal overtime arrangement. It was recognized that not every truck is operable all the time and that some loader, grader, or laborer manpower is utilized. Further adjustments such as reducing the number of personnel on overtime because of the use of patrols were made when such information was available.

The computed regular hours show relatively good correspondence with reported regular work hours because both are basically a product of the number of employees times 7.5 regular workday hours. Unknown augmentations of personnel or high percentages of personnel on leave, however, directly affect the reported regular hours.

The variability between the reported overtime hours and the computer overtime hours is a result of several factors, including the actual manpower level, management decisions on callout and other decisions, the accuracy of the CRTMP, and how accurately the input weather data reflect the condition seen by the managers.

The comparisons of regular and overtime hours alone do not reflect as accurate a measure as the total or reported regular and overtime hours compared with the total and computed regular and overtime hours for each county. Statistically it appears that on average the number of personnel on shifts are correct, and uniform practice exists regarding callout, cleanup times, and so on. Thus, on the average, variable weather severity is the major factor in determining the total hours.

The overtime hours used in this comparison are only those reported for providing winter traffic services--plowing, spreading antiskid materials, and storm cleanup--on the basis that overtime would only be authorized for these particular functions.

The percentage differences between the reported total of regular and premium hours and the computed total of regular and premium hours have a mean value of -2.92 and the deviation is ±10.94; thus the computed total of regular and overtime hours is less than the reported total by -2.92 percent on average and is within ±10.94 percent of the average of -2.92 percent, that is, between -13.86 and 8.02 percent of the reported total, in 68.26 percent of the cases.

The results indicate that the CRTMP is reliable.

Accident Analysis

Data were provided regarding accidents that occurred on snow- or ice-covered roads in the winters of 1979-1980 and 1981-1982. These data facilitated an analysis in which it was hoped that it could be determined whether counties using only single shifts had different accident rates from those using dual shifts.

No statistically definitive basis for identifying a relationship between accident rates and single or dual shifts could be found. It was concluded that weather variability is likely to mask any relationship that may exist between shift patterns and accident rates. Further, the sample size in relation to the range of variables was believed to be too small for reliable analysis.

Staffing Patterns

The cost-effectiveness of dual-shift staffing patterns as opposed to the exclusive use of single-shift staffing patterns was examined in relation to weather severity. On the basis of a statewide average, it was decided that a single-shift crew of 13 persons with 5 trucks available was representative. In order to operate dual shifts, it would be necessary to augment the initial 13-person single-shift crew with a minimum of a foreman and split the personnel evenly into two 7-person shifts. These crews may not be ideal or even practical in many instances, but they are possible and will illustrate the method of computing shift cost comparisons.

The average hourly wage was assumed to be the state average of $8.15/hr. The dual-shift differential of $0.35/hr was applied to dual-shift cost. The single- and dual-shift premium multiplier of 1.5 was applied. The hourly rates were as follows:

1. Single shift: $8.15/hr,
2. Premium single shift: 1.5 x $8.15 = $12.23/hr,
3. Dual shift: $8.15/hr base rate + 0.35 shift differential = $8.50/hr, and
4. Premium dual shift: 1.5 x $8.50 = $12.75/hr.

The single-shift crew of 13 persons thus costs 13 x $8.15 = $105.95 per regular shift hour. The dual-shift crew of 7 persons costs 7 x $8.50 = $59.50 per regular shift hour. The premium-time crew for both single and dual shifts was established at 7 persons for this example for consistency and comparison. The single-shift crew for premium time thus costs 7 x $8.15 x 1.5 = $85.58/hr. The dual-shift crew for premium time costs 7 x $8.50 x 1.5 = $89.25/hr.

The analysis program produces for any given calendar period and shift arrangement a total of regular shift hours and a total of premium hours. The total of regular hours excludes any hours worked on holidays and weekends in the period and is based on a 7.5-hr work day. The premium-time total accounts for all snow and ice time over 8 hr outside of regular shift hours on regular work days plus the impact of holidays and weekend days in the period.

Multiplying the appropriate total of hours by the associated hourly crew cost gives the total of regular-hour cost or premium-hour cost for the period, and the total of these two costs is then the total cost for the period.

These costs for our example are as follows:

1. Total single-shift regular-hour crew cost = $105.95 x total regular single-shift hours,
2. Total single-shift premium-hour crew cost = $85.58 x total premium single-shift hours,
3. Items 1 and 2 = total single-shift cost in the calendar period considered,
4. Total dual-shift regular-hour crew cost = $59.50 x total regular dual-shift hours,
5. Total dual-shift premium-hour crew cost = $89.25 x total premium dual-shift hours, and
6. Items 4 and 5 = total dual-shift cost in the calendar period considered.

The total cost of operating throughout a full winter with the single-shift crew arrangement described in the foregoing was compared with the total cost of the same winter when the personnel were augmented by a foreman and split into dual-shift crews. Two dual-shift periods were selected as representative of the dual-shift period used by most maintenance districts; these were the calendar periods December 1 through February 28 and December 16 through March 15. These costs were computed for each district by using the weather data from the representative weather station for that district in light, average, and heavy winters plus the data for the 1981-1982 winter.

The use of dual-shift periods can be justified on a cost basis in some instances. When winter severity (the incidence of snow or ice conditions) results in the requirement for so much single-shift premium time in a calendar period that by converting to dual-shift operation the reduction in premium hours required on dual shift is enough to compensate for the added shift differential and higher overtime hourly pay, dual shifts should be considered. In this example, the added cost of the additional foreman was included in the total cost.

In fact, the reduction of premium hours required to compensate for the added cost of extra personnel and the shift differential pay can be computed and is a function of the total single-shift premium time in the calendar period. For the periods chosen, the number of premium hours saved by going to dual-shift staffing must exceed a minimum of 70 and be at least about one-third of the total single-shift premium hours in the period. Other ratios will apply if the number of persons or the calendar periods are changed.

In summary, it can be shown that dual shifting may be cost-effective in counties with either consistently frequent snow and ice conditions or heavy winters if the dual-shift calendar period is chosen so that the number of premium hours saved by the dual shifting is sufficient to offset the cost of added personnel and shift differential pay for dual shifts.

Cost is not the only factor in evaluating the merits of dual shifting. Safety, efficiency, and the related productivity are considerations that may outweigh cost alone. Consider the case of District 2, Bradford Weather Station, winter of 1976-1977, when in the period of 13 weeks from December 1, 1976 through February 28, 1977 the analysis program showed that a single-shift crew would have been required to work 411 premium hours. This is an average of 31 premium hours per week. Assuming that there would have been two premium-hour shifts with premium time equalized, each man would have been required to work more than 15 premium hours each week. The extra hours make the average work week about 53 hr long. Because the weather is not evenly distributed, it can be assumed the requirement would be even higher in some weeks. The record shows 6 consecutive weeks in this period when at least 26 hr of premium time were required in the regular work week. This amounts to more than 50 hr per person in 5 days. In addition, three weekends in the period added in excess of 20 hr each, making 2 weeks of the period exceed 60 hr per man in the 7-day week. At this point the employees are putting in so many hours a day on a continuing basis that efficiency and safety may be affected. Dual shifting in this case reduces the premium hours to 261 for the period or 20 hr per week for an average of 10 hr per man, which is an average of 47.5 hr in a 5-day week. The demands of weekend premium time remain. The effect of reducing overtime demands on personnel and the benefit to efficiency and safety must be weighed against cost. In this particular case, the change to dual shifting has the added advantage of reducing cost. This is not always the case. Though weather variability will determine the actual effect as will the dual-shift hours, the conversion from a single shift from 8:00 a.m. to 4:00 p.m. to a dual shift from 4:00 a.m. to 12:00 noon and noon to 8:00 p.m. can statistically be expected to reduce premium hours by 22 percent. Thus when the single-shift premium hours in a calendar period become so great that they will require more than a desired amount of premium time per person per week, a conversion to dual shifts can be expected to provide a 22 percent reduction in premium time if the shift hours are as just stated.

It appears, as a value judgment, that average overtime of more than 8 or 10 hr a week, particularly when it may occur in the regular work week of 5 days, begins to affect personnel efficiency, safety, and morale. These then become considerations other than cost for converting to dual shifts.

Dual shifts produce other problems with regard to productivity and safety. The midwinter period when dual shifts are most likely to reduce premium time, for efficiency and safety reasons, as well as reduce cost is also the time when the greatest portion of working time will be in the dark. The computer analysis provides a total of the dark time in any period, adjusted as desired for morning and evening twilight, and the effect of shift hours on the total is readily apparent. The total reflects only those regular work days on which snow or ice does not occur, so it is directly related to the productivity of time not used for snow and ice control. During this time, the efficiency, if not the productivity, of personnel will be adversely affected by work in the dark. The analysis of work hours by function for single-shift compared with dual-shift counties, discussed in the section on work analysis, gives a measure of this effect. In addition, safety precludes the undertaking of some activities, such as pavement patching, in the dark hours. The decision to dual-shift must be tempered by consideration of the reduced efficiency, productivity, and safety of what can be accomplished in the dark, because this time period may constitute nearly half the available man hours on a given dual-shift day and perhaps as much as 30 percent of the total available man hours in a dual-shift calendar period.

The best practice regarding dual shifts seems to be that when the winter severity will require more single-shift premium time per man than is considered efficient and safe and/or the total premium hours in any selected calendar period is large enough so that dual shifts will reduce premium hours enough to fully compensate for extra employees and shift differential, dual shifts should be used for that calendar period. At this point weather severity has made snow and ice control paramount, and any loss of efficiency or production for other activities because they are being performed in the dark is less important.

Unfortunately, within a current winter season the evaluation of the severity of the winter is quite subjective. The climatic record and the use of a premium-hour threshold appear to offer the only means of establishing the best dual-shift period for a county.

On the basis of the analysis completed and the considerations presented, it was concluded that there are some counties that should definitely utilize dual shifts for a midwinter calendar period, there are some counties that might benefit from the use of dual shifts for a midwinter calendar period in some winters, and there are those counties that definitely will not benefit from using dual shifts in any period of any winter. This is shown graphically in Figure 3 in which the labor cost of winter maintenance operations for single and dual shifts is plotted against three types of winters--light, average, and heavy--for four representative weather stations. (It should be noted that the curves in the four plots are not consistently shaped because every winter is unique in some respect and the average winters do not bear the same relationship to the light and heavy winters for each weather station.) The plots indicate that the following shift arrangements would be appropriate for counties having the

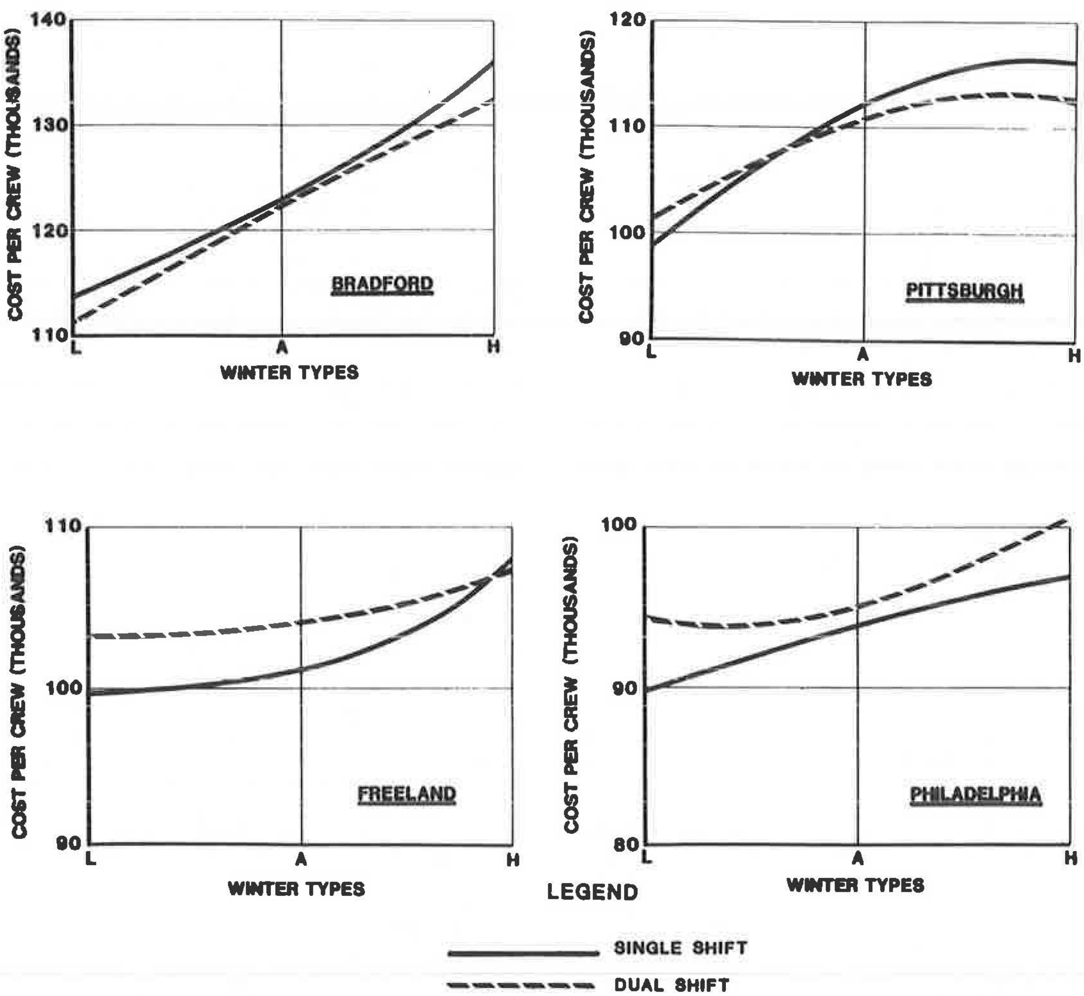

FIGURE 3 Staffing patterns: single- versus dual-shift cost comparison in dollars for four representative weather stations.

same weather as the representative weather stations indicated in Figure 3:

1. Bradford: Dual shifts are cost-effective and should be used,
2. Pittsburgh: Dual shifts are generally cost-effective and should be used for the major part of winter,
3. Freeland: Dual shifts may be cost-effective and should probably be used for the part of winter when severest weather is expected, and
4. Philadelphia: Dual shifts are not cost-effective and should not be used.

There is a similarity between the areas in which dual shifts are likely to be cost-effective, may be cost-effective, or are not likely to be cost-effective and the respective topographic areas discussed earlier--upslopes, uplands, and plains or bowls (Figure 1). This is helpful as a general guide as to which counties fall into each dual-shift category.

In this section procedures have been demonstrated for developing a staffing concept for single-shift and dual-shift crews and the premium-time crews required for each. The computer programs developed in this research have a large number of variable inputs and items to be selected on the basis of intimate knowledge of specific topographic areas, crew sizes, times actually required for clearing after storms, most appropriate representative weather stations, management decisions, and other factors, so it was considered impossible to respond to every county manager's concerns regarding staffing patterns and optimum working hours. As a result each district was furnished with diskettes containing weather data pertinent to that district and the computer programs so that the programs could be run in the district office on its personal computer.

Work Analysis

PennDOT provided data itemizing the hours charged to specific maintenance activities in each county for the period November 1, 1981 through April 11, 1982. Three pairs of counties, one using single shifts and one using dual shifts in each pair, were selected for comparison of time use. The selections were made on the basis of traffic counts, daily vehicle miles, urban population, and proximity so that similar weather would be expected.

Obviously, winter service hours reflect the first-priority requirements of the season. The amount of total time charged to winter services exceeded 50 percent in dual-shift counties, whereas it was somewhat less than 50 percent in single-shift counties; differences between pairs ranged from 9.3 to 16.9 percent of total hours. Differences in management, topography, and weather between the counties apparently account for such variations.

```
PROGRAM FOR MODELING STAFFING PATTERNS   FOR WINTER 11/01/76 THRU 03/31/77
                             DISTRICT  5   LEHIGH
                            * WEATHER STATION *
  ALLENTOWN                 STROUDSBURG

          [1] ICE STORM TEMPERATURE (°F) :          30
          [2] MORNING ICE TIME (HHMM):              0800
          [3] EVENING ICE TIME (HHMM):              1700

          [4] DATE  FROM(MMDDYY):                   121576
          [5] TO  (MMDDYY):                         022877
          [6] NUMBER OF SHIFTS:                     1
          [7] FIRST BEGIN REGULAR WORK DAY (HHMM):0800
          [8] LAST END REGULAR WORK DAY (HHMM):     1600
          [9] LIGHT STORM CLEARANCE (HHMM):         0130
          [0] HEAVY STORM CLEARANCE (HHMM):         0230
              TOLERANCE TIME IN MIN [A] 00    [P]   00

------------------------------ VALID COMMANDS ----------------------------
<O> START OVER                 <C> CREW HOURS REPORT      <Q> QUIT
<H> HELP WITH COMMANDS         <S> SUMMARY REPORT         <W> WEATHER STA.
<D> CHANGE DISTRICT            <L> MOD. DATA
What is your choice?
```

FIGURE 4 Program input display.

Results from the computer programs using the winter of 1981-1982 were combined with the data received from PennDOT for that winter to analyze the hours devoted to various maintenance activities. Because the computer programs furnished a complete summary of the weather and the hours of dark time when work on the roadway could not be performed, a number of useful comparisons could be made and conclusions, or at least inferences, drawn from them.

The analysis showed that dual-shift counties charge a larger percentage of total hours to winter services than do single-shift counties. It was concluded that this is at least in part a consequence of more severe weather in the counties compared. Dual-shift counties suffer a substantial penalty caused by dark hours compounded by weather factors in that the opportunity to perform other functions than winter services in light hours with reasonable safety and efficiency is significantly reduced. On dual shifts more than on single shifts, the hours when darkness, weather conditions, and safety preclude performing higher-priority work appear to be used on low-priority tasks. Dual shifts would therefore be limited to those areas and periods where the need to reduce overtime due to fatigue is apparent, a possible cost reduction may result, and the winter service activities are paramount to reduced maintenance productivity.

CRTMP Operation and Results

The CRTMP has the capability of providing a total of regular shift hours and premium hours that would accrue in any winter for which weather data are available and in accordance with the parameters selected. The parameters that may be selected are displayed on the computer terminal and may be changed through simple, conventionally recognized procedures.

The input display seen on the computer terminal is shown in Figure 4. The header (block 1, line 1) exhibits the inclusive period of weather data that was last placed in the Modified Weather File, the working file. The second line displays the maintenance district number that has been selected. The fourth line bears the names of the representative weather stations for the district selected. On the actual terminal the name of the weather station selected as a weather data base appears brighter than the others.

Block 2 of the input display has three lines pertaining to ice parameters. Line 1 displays the ice storm temperature in degrees Fahrenheit below which ice formation is considered to occur and which is variable to account for salting, solar heating, and traffic effects. Line 2 displays the morning ice time in hours and minutes, the time after which ice is not expected to form unless the maximum temperature is equal to or less than the ice storm temperature and which may be varied to account for effects such as sunrise, traffic volume, and shift times. Line 3 displays the evening ice time in hours and minutes, the time before which ice is not expected to form unless the maximum temperature is equal to or less than the ice storm temperature and which may be varied to account for daytime heating, traffic volume, and shift schedules.

Block 3 contains lines as follows:

Line 4 indicates the beginning date of the winter period to be analyzed in accordance with the parameters selected on lines 1 to 3 and 6 to 11;

Line 5 indicates the last day in the period to be analyzed in accordance with the parameters selected;

Line 6 displays 1 or 2 as selected for single or dual shifts;

Line 7 displays, in hours and minutes on a 24-hr clock, when the first regular shift starts;

Line 8 displays, in hours and minutes on a 24-hr clock, when the last regular shift ends;

Line 9 displays in hours and minutes the time added to the last hour of precipitation to allow for cleanup of a snowfall of less than 4 in.;

Line 10 displays in hours and minutes the time added to the last hour of precipitation to allow for cleanup of a snowfall of 4 in. or greater;

Line 11, Tolerance Time in Minutes, displays (A) the number of minutes before official sunrise to be subtracted from the time from beginning of the regular workday to sunrise and (P) the number of minutes of evening twilight to be subtracted from the time from sunset to the end of the regular workday.

Below the boxes are the valid commands designated by letter keys, which are self-explanatory.

Several reports are provided by the program:

- Crew Hours Report (Figures 5 and 6): Two reports are provided to show the substantial amount of dark time, indicated by Total AMTime and Total PMTime on the reports, that occurs when dual shifts are used compared with when single shifts are used. Dark time is only calculated on days when it does not snow.
- Summary Report (Figure 7): The winter SI is

```
DATE OF RUN FRI, SEP 07 1984 AT 10:37:04

   DISTRICT:  5      LEHIGH
   WEATHER STATION: STROUDSBURG
   DATE RANGE: 12/15/76 THRU 02/28/77
   ICE STORM TEMPERATURE  30 F
   MORNING ICE TIME:    8:00           EVENING ICE TIME:  17:00
   NUMBER OF SHIFT: 1
   FIRST BEGIN REGULAR WORK DAY:   8:00    LAST END REGULAR WORK DAY:  16:00
   LIGHT STORM CLEARANCE:  1:30     HEAVY STORM CLEARANCE:    2:30
   TOLERANCE TIME IN MIN:  0 AM       0 PM
   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

                                             TOTAL      TOTAL      TOTAL      TOTAL
                                             REG        AMTIME     PMTIME     PRTIME
*** TOTALS ***                               390:**      0:00       0:00     139:00
```

FIGURE 5 Crew hours report: single shift.

```
DATE OF RUN FRI, SEP 07 1984 AT 10:41:14

   DISTRICT:  5      LEHIGH
   WEATHER STATION: STROUDSBURG
   DATE RANGE: 12/15/76 THRU 02/28/77
   ICE STORM TEMPERATURE  30 F
   MORNING ICE TIME:    8:00           EVENING ICE TIME:  17:00
   NUMBER OF SHIFT: 2
   FIRST BEGIN REGULAR WORK DAY:   6:00    LAST END REGULAR WORK DAY:  20:00
   LIGHT STORM CLEARANCE:  1:30     HEAVY STORM CLEARANCE:    2:30
   TOLERANCE TIME IN MIN:  0 AM       0 PM
   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

                                             TOTAL      TOTAL      TOTAL      TOTAL
                                             REG        AMTIME     PMTIME     PRTIME
*** TOTALS ***                               780:00     39:15      99:07     108:30
```

FIGURE 6 Crew hours report: double shift.

```
DATE OF RUN FRI, SEP 07 1984 AT 10:37:01

   DISTRICT:  5      LEHIGH
   WEATHER STATION: STROUDSBURG
   DATE RANGE: 12/15/76 THRU 02/28/77
   ICE STORM TEMPERATURE  30 F
   MORNING ICE TIME:    8:00           EVENING ICE TIME:  17:00
   NUMBER OF SHIFT: 1
   FIRST BEGIN REGULAR WORK DAY:   8:00    LAST END REGULAR WORK DAY:  16:00
   LIGHT STORM CLEARANCE:  1:30     HEAVY STORM CLEARANCE:    2:30
   TOLERANCE TIME IN MIN:  0 AM       0 PM
   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

 121576 - 022877 DIST.  5  LEHIGH
SNOW STORM RANGE  SAT     SUN     MON     TUE     WED     THR     FRI    TOTAL
0.1" TO < 1.0"             1                                       2       3
1.0" TO < 6.0"     4       2       1       2       1               1      11
6.0"  >                            1                                       1
                  NO. TIMES NO. TIMES                   NO. TIMES  NO. TIMES
    HOUR          SNOWING    ICING          HOUR         SNOWING     ICING
0000 - 0100          6         0       1200 - 1300          2          1
0100 - 0200          4         0       1300 - 1400          2          1
0200 - 0300          4         0       1400 - 1500          3          0
0300 - 0400          3         0       1500 - 1600          3          2
0400 - 0500          5         0       1600 - 1700          4          3
0500 - 0600          2         0       1700 - 1800          2          5
0600 - 0700          3         0       1800 - 1900          3          4
0700 - 0800          3         0       1900 - 2000          2          3
0800 - 0900          3         1       2000 - 2100          1          7
0900 - 1000          4         2       2100 - 2200          2          7
1000 - 1100          1         1       2200 - 2300          2          6
1100 - 1200          2         0       2300 - 2400          2          6

TOTAL SNOW FALL (IN INCHES):      26.26  (     26.60)  NO. OF ICE STORM      0
NUMBER DAYS MIN TEMP BELOW 32 & MAX TEMP ABOVE 32       32
NUMBER DAYS MAX & MIN TEMP BELOW 32       32
*****************************************
*  W FACTOR =       182.600 24 hrs  *   *
*  W FACTOR =       154.600 1600 - 0800 *
*****************************************
```

FIGURE 7 Summary report.

DATE OF RUN FRI, SEP 07 1984 AT 10:37:58

DISTRICT: 5 LEHIGH
WEATHER STATION: STROUDSBURG
DATE RANGE: 12/15/76 THRU 02/28/77
ICE STORM TEMPERATURE 30 F
MORNING ICE TIME: 8:00 EVENING ICE TIME: 17:00
NUMBER OF SHIFT: 1
FIRST BEGIN REGULAR WORK DAY: 8:00 LAST END REGULAR WORK DAY: 16:00
LIGHT STORM CLEARANCE: 1:30 HEAVY STORM CLEARANCE: 2:30
TOLERANCE TIME IN MIN: 0 AM 0 PM
$$

				TOTAL REG	TOTAL AMTIME	TOTAL PMTIME	TOTAL PRTIME
12/15/76	WED		0.00	7:30	0:00	0:00	0:00
12/16/76	THR	ICE	0.00	7:30	0:00	0:00	6:00
12/17/76	FRI	LT SNOW	0.70	7:30	0:00	0:00	2:30
12/20/76	MON	ICE	0.00	7:30	0:00	0:00	7:00
12/21/76	TUE		0.00	7:30	0:00	0:00	0:00
12/21/76	WED		0.00	7:30	0:00	0:00	0:00
12/22/76	THR		0.00	7:30	0:00	0:00	0:00
12/23/76	FRI		0.00	7:30	0:00	0:00	0:00
12/25/76	SAT	ICE	0.00	0:00	0:00	0:00	4:00
12/26/76	SUN	LT SNOW	3.50	0:00	0:00	0:00	10:00
⋮			⋮	⋮	⋮	⋮	⋮
02/18/77	FRI		0.00	7:30	0:00	0:00	0:00
02/20/77	SUN	LT SNOW	1.00	0:00	0:00	0:00	2:30
02/21/77	MON	HVY SN	6.00	7:30	0:00	0:00	3:30
02/22/77	TUE		0.00	7:30	0:00	0:00	0:00
02/23/77	WED		0.00	7:30	0:00	0:00	0:00
02/24/77	THR		0.00	7:30	0:00	0:00	0:00
02/25/77	FRI		0.00	7:30	0:00	0:00	0:00
02/28/77	MON		0.00	7:30	0:00	0:00	0:00
*** TOTALS ***				390:**	0:00	0:00	139:00

FIGURE 8 Detailed report.

calculated by using two time parameters and is shown at the bottom of the report as the W-factor.

- Detailed Report (Figure 8).

CONCLUSIONS

A number of conclusions were reached and recommendations made as a result of the project described in this paper. Included among these were the following:

1. Weather varies greatly in Pennsylvania, and even adjacent counties experience different weather conditions as the result of storm movements and terrain features. Consequently, it was recommended that no attempt be made to establish a standard staffing pattern.
2. The winter SI provides a means of approximating the relative severity of winters. The correlation with actual data as well as with the CRTMP results makes it useful for evaluating performance.
3. The CRTMP provides reliable premium-time requirements when compared with the weather data and the input variables. Availability of the program in district offices will permit an almost limitless number of variables and staffing patterns to be tried in a short time at very little expense.
4. Snow removal and ice control usually cannot be deferred and thus take precedence over other maintenance activities. The impact of this requirement on the scope, productivity, and efficiency of other tasks cannot be completely avoided or mitigated.
5. The analysis comparisons and interviews conducted as part of the research indicate that the personnel at all levels in PennDOT are generally conscientious, dedicated individuals who have demonstrated ingenuity, cost consciousness, flexibility, and determination in an effort to get the job done as efficiently as possible with the available information and resources. Obviously, these individuals have already found effective solutions to many difficult problems.
6. Survey results show that on a nationwide basis, during the dark hours work other than performing winter maintenance is rarely done in the traveled way except under very unusual or emergency circumstances. As a result, dual shifts should only be used when genuinely appropriate as discussed elsewhere in this paper.
7. Dual-shift operation for at least part of the winter season can be more economical than single shifts in some districts or counties, and specific recommendations were provided to PennDOT.

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An Overview of Semiautomatic Fueling Systems

MAGGIE LAIRD and T. H. MAZE

ABSTRACT

An overview of the options to be considered in procuring a semiautomatic fueling system is provided. The system options are divided into three areas: software, system access and data entry, and hardware. The pros and cons are discussed for common options in each of the three areas.

Of the costs associated with operating and maintaining vehicle fleets, fuel generally has the conspicuous distinction of being the second largest single item. Labor costs (driver and mechanic wages) are generally highest. Further, even though fuel prices in real dollars (dollars discounted for inflation) have risen only marginally in the last 10 years (1), the rising price of fuel in absolute dollars since the 1973 Arab oil embargo has had significant psychological impacts on budget analysts of energy-intensive industries. Both the size of fuel costs in operating budgets and increasing fuel prices (in absolute dollars) have made fuel a likely candidate for cost cutting by agencies facing pressures to economize.

A popular option to aid in the control of fuel costs is the use of semiautomatic fueling systems. Although the capabilities of these systems vary dramatically, at a minimum they record, through automatic data entry at the fuel pump, the quantity of fuel use by individual vehicles and the dates on which vehicles are fueled. This allows the fleet manager to track quantities of fuel delivered and used.

Because the capabilities of such systems vary, the options to be considered in buying them are many, which makes the purchase decision complex. This paper is designed to be a first step in the information-gathering process for an agency contemplating the procurement of a system. The paper covers system planning and design options that are available and briefly covers the pros and cons of each option. The options are divided into three areas: software, system access and data entry, and hardware.

SYSTEM PLANNING AND DESIGN

During the system planning stage, the performance specification is developed, and during the design stage the physical configuration is determined. The possible choices to select from during the planning stage are many. For example, the agency must decide which level of sophistication of the system's performance will most efficiently meet their needs. The performance may vary from simple transaction recording to provision of sophisticated management information. The physical configuration must be chosen from numerous possibilities. For example, the agency has the option of buying or leasing a system, and the system may operate on separate hardware or be tied in to existing hardware and even integrated with existing software.

The semiautomatic fueling system's ability to meet the agency's needs is largely constrained by the computer programs (software) used. Regardless of the sophistication of the hardware or of the system access devices, if the software is unable to prepare information required by the performance specification or the system cannot be integrated with existing hardware or software or both, the system will not meet the agency's needs. Therefore, when the system performance specification and design are being developed, it is important to first consider the performance of the software. The next most important consideration in constraining the abilities of the system is the access and data entry system. This system will control the types of data collected and limit the flexibility of the system. The last in importance is the selection of data-processing equipment (hardware). Because the performance of software has been selected, hardware choices are largely constrained to those that are compatible with the performance of the selected software.

In the order of their importance in the selection of a system, semiautomatic fueling system software, system access and data entry, and hardware are discussed in the following subsections.

Software

The key element in the planning and design of a semiautomatic fueling system is the capabilities of the software selected. Software performance requirements should not be made to meet the capabilities of commonly available (or inexpensive) software. They should be designed according to the current and projected needs of the agency. For example, the tracking and control of fuel storage quantities, delivery quantities, and transfer quantities are difficult when multiple storage tanks are used to hold the same fuel product and very difficult if multiple tanks are dispensed through one pump. If the agency plans to use multiple tanks, the software specification must take this factor into account.

Software with flexibility and the ability to be custom tailored is generally more capable of fulfilling the agency's needs for two reasons. First, flexibility will allow the software to change through time as the agency's needs change. Second, software that can be custom tailored will conform to the agency's needs rather than the reverse.

Simple software systems will store and report transaction lists. For each time that fuel is accessed, the transaction list will generally indicate the vehicle identification code, the date, number of gallons delivered, the fueling location (if there is more than one), and the employee's identification code. More sophisticated systems can provide management summary information, send messages to drivers and fuelers, control the quantity of fuel delivered to vehicles, and analyze fuel consumption statistics. More specifically, some of the more sophisticated systems include the following options:

1. Validation: Data validated include

a. Current mileage (or hours) entered (for example, the system should not accept a mileage that is less than the one entered in a prior transaction or a mileage that indicates that the vehicle has traveled an unrealistic distance since the last transaction),

b. Vehicle codes and employee authorization codes,

c. Fuel products used and the quantities delivered (for example, the system should not allow the delivery of diesel fuel to a vehicle that is listed in the master file as a gasoline engine automobile nor should it allow the delivery of more fuel to a vehicle than the maximum the vehicle could have used given the mileage traveled since the last transactions or more fuel than the capacity of the vehicle's fuel tank);

2. Management information: The fueling system can provide information to assist the fleet manager in better managing his fleet. If properly utilized, the fueling system can provide high-level fleet management information that can involve substantial payoffs for the entire organization. The information that can be provided includes

a. Comparative statistics identifying fuel consumption trends and traits of the fleet, vehicle models, and individual vehicles (vehicle operating costs are highly dependent on fuel costs; thus this information can be used in such high-level management activities as determining vehicle economic replacement intervals and life-cycle costing);

b. Billing and expense reports; and

c. Exception reports, which identify the occurrence of fuel consumption (or consumption of other fluids) outside of normal tolerances; these reports are an important element in determining bus performance and in diagnosing impending mechanical problems;

3. Messages: When a particular driver, fueler, or vehicle is identified at the fuel access point, the system may provide messages indicating some special characteristic (for example, the message may tell the fueler that the vehicle is due for preventative maintenance and needs to be positioned in a special location or that the vehicle is part of a special test and should not receive normal lubricants).

When a software system is purchased, it is important that it be able to meet the agency's information requirements. However, it is a complex task to plan and design a fueling system so that the full potential of the system's capability to provide management information is realized. It requires a full understanding of the information needs and the flow of information within the agency. Therefore, care must be taken in developing the software's performance specification.

System Access, Data Entry, and Fueling Control

The device allowing access to the system is the primary point of control and security. Because of its importance, the type of system used to permit access should be carefully selected to meet the needs of the agency. There are a variety of access systems with varying degrees of sophistication and each has good and bad points.

The system chosen for access control can also constrain the types of data collected at the access point. For example, the primary purpose for key and card systems is to control access to fuel. If the fueling system is intended to collect more than simple transaction information (e.g., current vehicle mileage and other fluids used) the key or card system must be augmented with a data entry pad and information display. However, once a data entry pad is available, it may be possible to control access to the system by typing in authorization codes, thus relieving the need for the key- or card-controlled system. Therefore, key and card systems may not be appropriate if the system performance specification calls for higher-level information.

In the following paragraphs the good and bad points of popular access systems are discussed.

Popular Access Systems

Plastic Card Systems

Plastic card systems use hole patterns punched through the cards or a magnetic strip on the card. Encoded in the holes or on the magnetic strip is the identity of the vehicle. Card systems are inexpensive and functional; however, the integrity of these systems can be easily jeopardized through misuse and abuse of the cards.

The cards are extremely susceptible to misuse. For example, they can be used to open locked doors, as ice scrapers in the winter, and to fuel unauthorized vehicles. Further, they become brittle in extreme heat or cold, thus making it easy for them to become bent or broken. Also, the punched cards can be easily duplicated by punching holes in the same pattern into another card or through a piece of paper.

Individual Key Systems

In key systems, a key is encoded with the identity of each vehicle. This system is inexpensive and can be efficient if only one driver is given responsibility for a key and always drives the same vehicle. However, if many individuals drive many different vehicles, a key system can become cumbersome and clumsy. The key can be easily lost or forgotten and therefore a backup set of keys is generally maintained.

Keylike Memory Devices

Plastic data keys are made that contain microchips. Information can be read from and written on these chips. Each vehicle is assigned a key and the key's chip contains the vehicle's authorization code. Keys can be coded at the user's site, thus making it easy to replace lost ones. Lost keys are automatically disabled, which reduces unauthorized fueling.

Keypad Systems

Many systems use a keypad for data entry at the fueling island. Keypads are either the standard raised mechanical-key type or touch-sensitive pads. In keypad systems there are no devices to bend or lose, there is no chance of reproducing a card, and most people are familiar with similar systems (such as automated teller machines at banks and supermarkets). These systems are more expensive to purchase than card and key systems; however, the security and the system integrity are higher.

Bar-Code Readers

Although the technology used in bar-code readers has been applied to other systems, its use in semiautomatic fueling systems is recent. The bar-code strips resemble those used on food products in grocery stores. Some bar codes are mounted on the inside of the fuel door. Others are mounted on the side of the vehicle. These can be read with a hand-held bar-code reader wand or a wall-mounted reader.

Access and Control Systems in Development

Because the access and control points determine the integrity of the systems, efforts are currently under way to make access systems more tamperproof while improving the reliability of the data entered into the fueling system's data base. Some of the systems currently under development are as follows:

1. Microwave data communication between fueling trucks and the fueling system at the home base. Microwave communications will allow the mobile truck system to perform like a fixed on-line system.
2. Data storage devices that contain information regarding the vehicle mounted in a rubber seal inside the vehicle's fuel inlet. A matching device is sealed onto the pump nozzle, which, when it is inserted into the vehicle's inlet, exchanges the information and allows the vehicle to be fueled.
3. Sensor systems in the fueling tank that permit the system to identify how much fuel is dispensed from the storage tank. The identification of the tank from which the fuel is drawn becomes a problem when multiple tanks are used to feed one pump.

All types of access systems, to some extent, have difficulties with harsh weather and other environmental conditions. For example, moisture from humidity, snow, rain, and sleet can hamper the accuracy of card and key systems. Dirt and oil can block a bar code, making it impossible to read. To mitigate these problems, enclosures and other protective devices should be provided.

System Hardware

By the time hardware planning and designing have been reached, the hardware choices have been dramatically narrowed by prior software and access system choices. However, there is still some latitude in the choice of hardware configuration, of which there are three distinctly different types.

Local Microprocessor at the Fueling Site

This is a stand-alone system that allows one-way communication from the pump to a local microprocessor. Because the microprocessor is designed to control a specific pump type and to provide specific types of information, it is difficult to make system updates and software changes without replacing the microprocessor.

A stand-alone system allows each garage to be independent in the control of its own fuel. There may be advantages to this type of system if each garage manages its own fuel. However, each vehicle must be assigned to a specific site for fueling. If a vehicle were to fuel at another location, the system security would have to be overridden and management information data would have to be manually entered at the vehicle's home fueling system.

Central Processor Off Site

Control of the pumps from a centralized processor, which generally is capable of being programmed, permits software updates. Further, if the central processor has the capability to manage data bases, the system can be used to provide higher-level management information.

The difficulty in using a centralized system lies in problems encountered with system failures. A failure of either the central processor or of the data communication lines will result in an inability to deliver fuel at remote sites. The possibility of a system failure necessitates manual overrides at remote locations, which reduces the integrity of the system.

Centralized Processor Off Site with Communication to On-Site Microprocessors

Combination of the previously described system with an on-site microprocessor allows centralized control and centralized processing of information while allowing each remote fueling site to operate independently. This system creates fault tolerance in the system control and thereby increases the system's reliability (the probability of operating normally over a specific time interval).

CONCLUSIONS

This paper is intended to provide a brief overview of available semiautomatic fueling system planning and design options. It is recommended that the potential buyer first investigate the agency's fuel-related current and projected information needs. Next, the system performance specification should be planned followed by the design of the system's physical configuration. The planning and design stages should first consider software, next system access and data entry, and last hardware.

ACKNOWLEDGMENT

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Idaho's Equipment Management System: A Review

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ABSTRACT

The Idaho Transportation Department completed work on a contract with FHWA in March 1980 to test and evaluate an Equipment Management System (EMS). Idaho's EMS has been in operation since July 1980. In this paper the system is outlined, and benefits, problems, and changes since 1980 are discussed.

The Idaho Transportation Department (ITD) has historically provided some type of information for equipment managers. The majority of the information was financial and not timely. The output was rigid and often voluminous. Equipment managers were not getting the information that they needed to make decisions. During the 1970s replacement costs soared and the revenue to operate and replace equipment dwindled.

Interest was growing nationwide in the equipment management system (EMS). During this period, FHWA sponsored a pooled-fund study on the EMS. ITD contracted with FHWA in March 1979 to test and evaluate an EMS based on the FHWA EMS manual.

ITD's contract with FHWA was for 1 year. Because the supply and financial functions were already being developed, the contract was short term. It was finalized in March 1980 and the final report was submitted to FHWA in May. Work continued on the EMS after the contract had been completed. The system became operational in July 1980. The ITD EMS is very much a product of the work performed under the FHWA contract.

IDAHO'S CURRENT EMS

The ITD EMS consists of one major system that gathers information from four sources:

1. Highway maintenance districts: Idaho is divided into six districts. A major repair shop is located at each district headquarters. These shops perform repair and maintenance of equipment for the district. Each district office is linked to the main computer at ITD headquarters in Boise. This computer network has been in place since 1977.
2. Transportation Resource Management System (TRMS): TRMS is a financial management system. It replaced the old accounting system in July 1981. The processing in this system is primarily batch, done nightly.
3. Supply system: The supply section receives and issues all supplies for ITD. The supply system provides information to EMS on fuel use, disposal, and replacement of equipment and on parts and supplies. Batch processing is done nightly before TRMS runs.
4. Capital Properties Inventory System (CPIS): CPIS is an inventory system. It is a batch system updated by the districts as equipment locations and attachments change. These locations and attachments are then made a part of the EMS.

Input

Five input forms provide EMS with information from the field. The data from these forms are entered in each district office through ITD's computer network. The forms are

1. Job order form,
2. Preventive maintenance (PM) form,
3. Employee time sheet activity report,
4. Supply request form, and
5. Fuel issue form.

The data collected by the district goes to EMS, TRMS, and the supply system. Information from the PM form goes directly to EMS. Data from the job order and employee time sheet activity report go to TRMS before being passed to EMS. The supply system receives information from the fuel issue form and the supply request document. This information is later passed to EMS. Although information from all five forms is important, the job order and PM forms contain most of the significant information for EMS.

Job Order Form

The job order form (Figure 1) is one of the primary documents for EMS; it provides basic information. The job order number is a preprinted number that designates a particular job. This is the number under which all data are stored. The first digit designates the district and the other four are sequential.

Next on the form are the number of the piece of equipment on which work is being done, a short description of the equipment that is being serviced, and the odometer or hour meter reading of the equipment, which is always reported to the nearest whole number.

A vehicle accident number is assigned by the district personnel or the department safety supervisor to aid in capturing department accident costs. The numbers under Work Authorization, Distribution Rule, and Function Code are accounting codes. The organization code of the shop performing the work and the organization code or appropriate accounting code for an outside agency, which indicates to whom the equipment is assigned, are included also. Transaction codes are those that are assigned to aid in distributing the costs correctly in the accounting system.

Under the heading "Dates" are "J.O. Initiated" and "J.O. Complete." "EST. Complete" is reported on the weekly out-of-commission report for information.

The type of service to be done is to be circled, and there is only one per job order. If the need for repair is discovered during or because of periodic preventive maintenance, the basic reason for repair is preventive maintenance.

Under the heading "Date" is listed the date the work is being performed. The section headed "Labor"

OH-656 12/80 **OPERATION'S JOB ORDER** 4 of 4

JOB ORDER NUMBER
EQUIPMENT NUMBER
METER READING MILES/HOURS
DESCRIPTION
VEH. ACCIDENT NO.
LOCATION: ROUTE
STOCKPILE NUMBER

WORK AUTHORIZATION
DISTRIBUTION RULE
FUNCTION CODE
ORG. REPORTING
ORG/AGENCY ASSIGN.
MILEPOST LIMITS

TRANSACTION CODE:
CAML -- (MAT'L LAB)
CASS-- (SIGN SHOP)
CAJO-- (SHOP J.O.)
CATC-- (SIGNALS)
CAMF-- (MANUFACT)
CASP-- (STKP.PRO.)
CAMT-- (MISC.MTCE)
CAUS-- (OF SUPT.)

DATES		TYPES OF SERVICE (CIRCLE ONE)	
J.O. INITIATED		PREV.MAINT. 1	CONVERSION 5
EST. COMPLETE		BREAKDOWN 2	MODIFICATION 6
J.O. COMPLETE		ACCIDENT 3	PRODUCTION 7
		WARRANTY 4	NEW INSTALL. 8

DATE			LABOR				WORK	EQUIP. RENTAL	
MO.	DAY	YR.	LAST NAME (1ST TWO)	SOC. SEC. NO.	ACT. NO.	HOURS	UNITS COMPLETE	EQUIP. NO.	MILE/HOUR

WORK DESCRIPTION: __________

APPROVED BY

REQUESTED BY

DOCUMENT NO.

(STAYS WITH EQUIPMENT)

FIGURE 1 Job order form.

contains name, Social Security number, activity number, and hours for work performed. Under "Last Name" the first two letters of the worker's last name would be given. The Social Security number along with the two-letter abbreviated last name provide a track as to who performs the work. Under "Hours" is given time spent on the activity, which is reported to the nearest whole hour when possible.

The number of work units completed for a particular activity are listed, and under "Equipment Rental" the number of the equipment and the miles or hours that it is used in the repair of another (for example, a transport or a shop truck) are given.

A written description of the work to be done is given on the form. This would be done after consultation with the operator or foreman requesting the job order. The mechanic can also write down additional work performed.

The form is signed by the shop superintendent, foreman, or mechanic who sets up the job order and says that the work will be done. The equipment operator or supervisor who is requesting the work to be done also signs.

This job order is a modification of previous job orders used. It is designed to fill information needs for many different departmental functions.

PM Form

The PM form (Figure 2) is used to provide information about oil changes, lubes, inspections, and

ITD-659 5/80

PREVENTIVE MAINTENANCE
EQUIPMENT MANAGEMENT

EQUIPMENT NUMBER [| | | | |] DESCRIPTION ____________

METER READING (MILES / HOURS) [| | | | |]

PM (A) E981 PM (B) E982 PM (C) E983 PM (D) E984 PM (E) E985

DATE			LABOR				WORK UNITS COMPLETE	REMARKS
MO.	DAY	YR.	LAST NAME (1st TWO)	SOC. SEC. NO.	ACT. NO.	HOURS		
				/ /		.		
				/ /		.		
				/ /		.		

COMMENTS ____________

PERFORMED BY ____________ CKD BY ____________

FIGURE 2 PM form.

major PM functions. It lists the equipment number, meter reading, and a description of the equipment (Chevrolet, Ford, etc.).

The form reports who did the labor, the activity number for type of preventive maintenance, the number of hours used to perform the activity, and the work units. It also gives a written description of the work that was done or needs to be done. This form is separate from the job order so a history can be maintained on a specific piece of equipment.

The PM form is intended for all inspections (except a special major inspection) as well as for tire work. The operator fills out this form and keeps a copy for himself. Information from the form updates the PM schedule.

Output

The output from EMS is primarily batch reports of the type shown in Figure 3. They are produced weekly, monthly, quarterly, and yearly. To cut down on paper flow and make the reports more usable, summary and exception reporting is stressed. Depending on their information needs, different levels of management receive different reports. A list of all current reports produced is given as follows:

1. Management level
   a. Equipment rental rate variance report (quarterly): variance in cost and budget based on the actual rental rate;
   b. Rental rate analysis for operating cost (quarterly): calculated rental rate versus the budget rental rate;
   c. Repair frequency--labor (yearly): number of repairs and labor hours expended by class, category, activity, and district;
   d. Repair frequency--cost (yearly): computed repair costs based on labor and parts costs;
   e. Complement list (yearly or as needed): complete list of equipment by district; and
   f. Utilization analysis (yearly or as needed): equipment use by class and district compared against a standard established by the equipment superintendent.
2. District management level
   a. Out-of-commission report (weekly): equipment with open job order and estimated return date;
   b. PM schedule (monthly): list of equipment

DD-0608
HC001 022A

Report Page 01
Date 10/15/80
Time 14 25 50

DISTRICT 1

THE FOLLOWING VEHICLES ARE DUE FOR P.M. TYPE A THIS MONTH:

CLASS	CATEGORY	EQUIP. NUMBER	DESCRIPTION	LAST PREVENTATIVE MAINTENANCE DATE	METER	TYPE	LAST REPORTED METER READING	SCHEDULE BASIS	OVERDUE MILE/HR
AA	100	H01720	SEDAN, OLDS CUTLASS	3/03/80	17867	A	23149	6000	____
		1843	SEDAN, FORD	5/15/80	67214	C	73429	6000	215
	200	H04136	PICKUP 1/2 TON CHEV	5/10/78	7950	A	10725	3000	

THE FOLLOWING VEHICLES ARE DUE FOR P.M. TYPE B THIS MONTH:

CLASS	CATEGORY	EQUIP. NUMBER	DESCRIPTION	LAST PREVENTATIVE MAINTENANCE DATE	METER	TYPE	LAST REPORTED METER READING	SCHEDULE BASIS	OVERDUE MILE/HR
BA	320	H06160	DUMP TRUCK 4 x 2	6/20/78	73141	A	27150	4000	9

FIGURE 3 PM schedule, October 1980.

for shop foremen that will require preventive maintenance;

c. Fluid use report (monthly): use of engine fluids (fuel, oil, antifreeze, etc.) by class;

d. Equipment maintenance analysis (monthly): total number of repairs (labor, hours, costs, and occurrences) and averages per repair; and

e. Report of downtime activities (yearly): listing of year's downtime by activity code.

3. On request

a. Job order analysis (complete report of the labor and parts expended on a particular job),

b. Most recent preventive maintenance reported (date of most recent work by equipment number),

c. Equipment master list (complete list of equipment by class, category, and district), and

d. Equipment maintenance history (entire maintenance history of a piece of equipment by activity).

The users can also generate their own reports with user-friendly languages. The EMS database and detail record were designed to allow users easy access with their own programs. This allows them to create reports that are timely and relevant. It also reduces the workload for the data processing staff. The master detail file contains the following information:

1. Equipment
   a. Class
   b. Category
   c. Number
   d. Description
   e. Serial number
   f. Model year
   g. Acquisition cost
   h. Acquisition year
2. Assignment
   a. District
   b. Organization
   c. Station
   d. Funding source
3. Preventive maintenance
   a. Schedule
   b. Interval
   c. Prior preventive maintenance
      (1) Date
      (2) Type
      (3) Meter reading
4. Fluid use
   a. Type
   b. Quantity
   c. Cost
5. Maintenance
   a. Usage
   b. Income
   c. Labor
   d. Parts
   e. Commercial repairs
   f. Accidents

BENEFITS OF EMS

Idaho's EMS provides managers with more timely and usable information about their fleet. EMS gives a way of tracking downtime, which may be due to several reasons, chiefly lack of parts or personnel. If one particular brand is consistently down because of lack of parts, this brand can be avoided in the future. For example, it was found that one make of equipment was down over 6 months awaiting a part whereas other makes experienced little or no downtime for that reason.

EMS captures costs. If a chainsaw costs $300 and $480 is spent on repairs and maintenance over one season, EMS provides this information to managers. Managers can track costs for different brands and decide how to spend money for equipment more effectively.

Using information from EMS, managers decided to purchase all trucks larger than pickups with diesel rather than gasoline power. EMS provided information on costs for purchase, maintenance, and operation for both diesel and gasoline trucks over the life of the equipment. This information was persuasive enough to convince the state purchasing agent to allow ITD to specify diesel-powered trucks for bidding purposes.

EMS provides information as to which districts use and need specialized equipment. Districts that show greater use of snow removal equipment get newer equipment and rotate their older, higher-mileage equipment to districts that do less snow removal. The use of specialized equipment such as roadgraders is tracked by EMS. Managers can decide whether to keep specialized equipment on the district's complement or to rent it when needed.

Utilization of other types of equipment is shown by EMS. All types of vehicles appear on the EMS database. After a utilization report was run on sedans, one administrator returned the car assigned to him to the motor pool.

PM information is captured and recorded by EMS. An oil sample is taken at every oil change for each piece of equipment and sent to the chemistry laboratory in Boise, where it is analyzed. The analysis shows any contamination in the oil sample, and engine problems can be pinpointed before they become serious. The analysis can also show whether the oil-change interval should be altered and can indicate which weights of oil are best for different conditions.

PROBLEM AREAS AND CHANGES TO EMS

To correct a problem in obtaining accurate meter readings, ITD implemented an editing procedure that eliminates meter readings that exceed a reasonable range. The acceptable range is between 0 and 600 miles since the last meter reading, and any meter reading that is not within this range is edited out. The meter reading is then corrected and reentered. This procedure assures reasonable meter readings. For accurate instead of merely reasonable meter readings, EMS depends on the districts to edit their data before submitting the readings to EMS.

Some users have had difficulty in assessing EMS. As the users have become more familiar and skillful with proper languages, problems have declined. Training classes have helped users become proficient in accessing the EMS database.

ITD changed from single to dual rental rates. Dual rates capture total equipment cost better than a utilization-based single rate. A fixed ownership rate is carried by the dual-rate system. This ownership rate covers the cost of replacement, storage, and insurance. The operations rate covers the costs of parts, supplies, fuels, maintenance, labor, and all other related costs of operation.

SUMMARY OF IDAHO'S EMS EXPERIENCE

The ITD EMS has helped provide equipment managers with timely, accurate information. Relevant information is presented in summary or exception reports. Users can access the EMS database for special reports. This makes the EMS flexible and responsive.

Problems have occurred in the interface between EMS and other systems. The introduction of TRMS altered much of the data collection for EMS. Data that once came directly from the districts now pass through the TRMS.

ITD is beginning to utilize 4 years of historical data for better equipment management. Idaho's EMS has become an integral part of all the management systems within ITD. ITD strives to keep EMS both useful and timely, providing equipment managers with information they need to achieve the greatest productivity at the lowest cost.

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Some Simple Methods of Maintenance Management Appropriate for Developing Countries

R. ROBINSON and M. S. SNAITH

ABSTRACT

Maintenance management in developing countries is discussed and some objectives for a maintenance management system are given. Two simple management systems appropriate for use in developing countries are described. The first is a manual system based on Transport and Road Research Laboratory Overseas Road Note 1 and the second is microcomputer-based and called System BSM. The methods of operation of these two systems are discussed under the headings of inventory, inspection, maintenance needs, costing, priorities, execution, and monitoring.

The successful introduction of a maintenance management system into a developing country should achieve several objectives. Among these will be the following:

1. The system will provide the means for estimating the actual maintenance budget that is required. This budget will depend on the types of maintenance procedures used, the frequency with which these are carried out, and the size of the management and organizational overhead needed to support the maintenance activity.
2. The system will also provide factual data to support budget requests when these are made to senior roads organization staff or to ministries of finance. These data will be obtained as a result of determining maintenance needs by using quantitative field inspections and monitoring work completed to ensure that it has been carried out in a cost-effective manner.
3. The system will also ensure an equitable distribution of budget over the whole country, recognizing that needs and costs will be different from region to region depending on geographical location, climate, topography, soils, and the particular nature of the network within the region.
4. The system will recommend priorities for work in the event of a shortfall in budget allocation by ranking maintenance activities on different roads. This will depend on the importance of the region in which the road is located, the political or strategic importance of the road in question, the traffic and axle loading, the type of road surface, and the rate of road deterioration that would be caused by deferral of the work. This last item will also depend on the climate, topography, and soil type in the area in which the road is located.
5. The system will contain a mechanism for monitoring the road network to ensure that all planned work is in fact carried out, that it is carried out efficiently, and that the work is achieving the desired results.

A maintenance management system normally contains the following components:

1. Inventory is used as the basic reference for planning and carrying out maintenance operations and inspections;
2. Inspection of road condition should be done by taking physical measurements of defects on the road network in the field;
3. Maintenance needs are determined by comparing the measurements of road condition with predetermined maintenance intervention levels;
4. Costing is applied to the identified maintenance tasks to determine the budget required;
5. Priorities are determined if the budget is insufficient for all of the identified work to be carried out; it is then necessary to determine which work should be undertaken and which should be deferred;

6. Execution of the work is identified by using several systems of scheduling and cost accounting;

7. Monitoring serves two purposes:

a. It ensures that work identified has in fact been carried out, and

b. It provides data to enable unit costs and intervention levels to be checked and adjusted if necessary.

This sequence of activities will be illustrated by two maintenance management systems that have been devised specifically for use in developing countries. Overseas Road Note 1 (ORN1) (1) is a maintenance manual prepared by the Transport and Road Research Laboratory's Overseas Unit in conjunction with Scott Wilson Kirkpatrick and Partners. It is aimed at district engineers in developing countries and was written to help them improve road maintenance carried out in their district by using simple management and organizational techniques. Although its original purpose was to supplement the maintenance system in use within their organization, ORN1 can in fact be used as the basis of a manual maintenance management system. System BSM (2) was developed by Highway Management Services Ltd. and essentially builds on the ideas and methods in ORN1 to provide a system for managing recurrent, periodic, and special maintenance with the assistance of a microcomputer. In addition, it is able to combine data from devices such as the Benkelman beam and bump integrator with manually gathered information to arrive at the detailed selection of remedial works.

INVENTORY

An inventory lists those features of the road that do not change with time and is used as the basic reference for all subsequent surveys, inspections, and plans. Without an appropriate inventory, it is not possible to draw up meaningful programs for

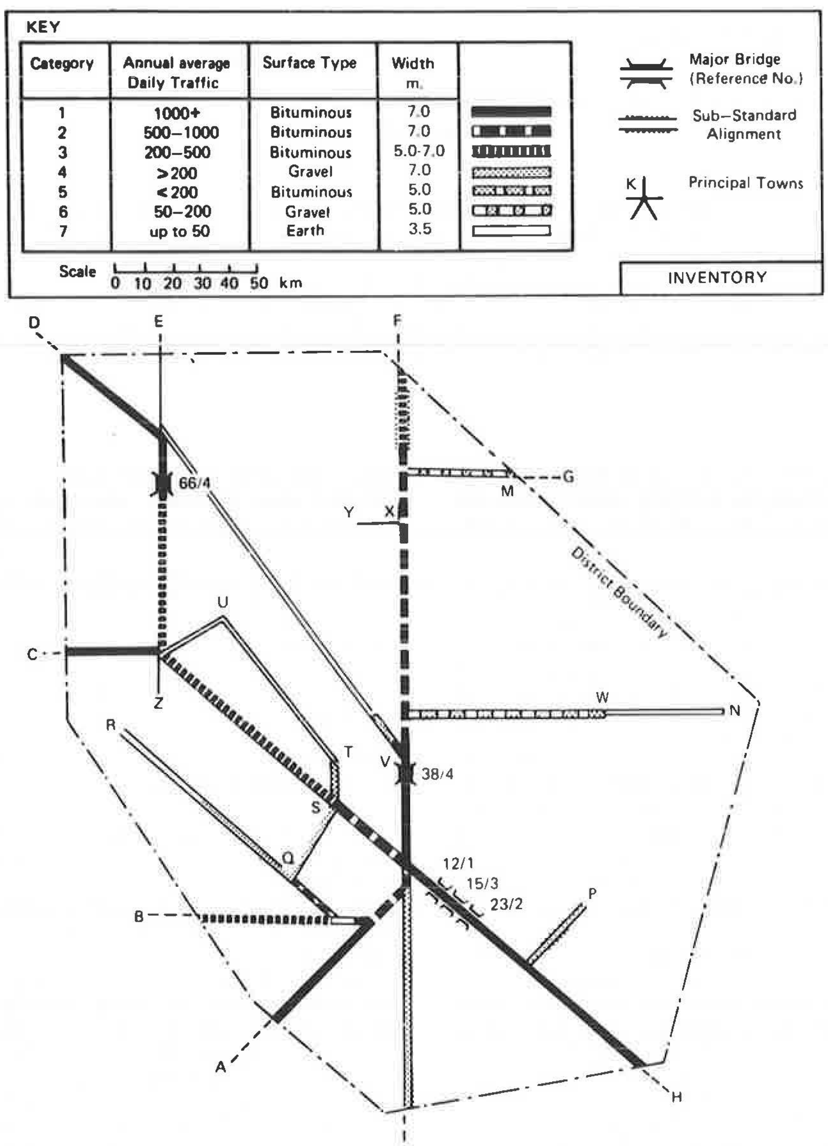

FIGURE 1 Simplified road map of maintenance district.

carrying out the work in a systematic and cost-effective way.

ORN1 recommends that the inventory need only contain that information required for planning the maintenance needs of the network. It should be kept as simple as possible because the gathering of unnecessary information is a costly exercise. The information should be presented in a simple way and ORN1 recommends the use of diagrammatic maps (Figure 1) and strip maps (Figure 2). These can be marked up to show construction type and widths of lanes and shoulders, location of bridges and culverts, plus information on soil conditions, sources of materials, and so on.

In a similar manner, System BSM accepts inventory information and attaches it to the appropriate unit of road length, known as a subsection. If information on road construction type and traffic levels is available, this may be stored within the data bank in addition to information on geometrics and drainage features. Inventory information may be printed for each individual subsection or for an entire route network depending on the use for which it is destined.

INSPECTION

Inspections must be carried out to determine the level of road deterioration so that maintenance needs can be determined.

The need to make physical measurements of defects, where possible, is emphasized by ORN1, although for some features only a visual assessment is possible. ORN1 contains suggested inspection forms for both paved and unpaved roads and gives detailed notes for carrying out defect measurement by using a measuring tape, a straightedge, and other simple equipment. It is noted that defect measurement should be related to maintenance criteria that establish when and where repairs are needed. These are used to determine which maintenance technique should be applied. It is recommended that the entire network be inspected and that defects be summarized and recorded for each 200-m length of road.

The System BSM subsection is also frequently taken as 200 m and a similar method to that of ORN1 is adopted for the collection of condition information to enable rational decisions to be made. The only difference in the mode of primary data collection is that one data sheet for each subsection is required to collect all condition information necessary for assessment purposes. However, System BSM also attempts to draw attention to those portions of road that require an in-depth study to determine periodic maintenance and strengthening needs. Consequently, there is the facility for the entry of data derived from more sophisticated measuring instruments to enhance the total sum of information held for any one subsection and thereby improve the selection of appropriate treatments. As with inventory data, this may be output either for any one subsection or for an entire route network.

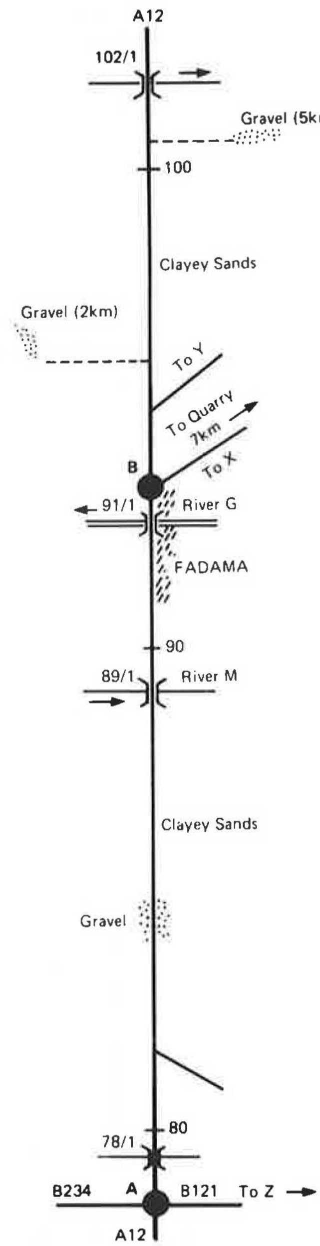

FIGURE 2 Simple strip map of road inventory.

MAINTENANCE NEEDS

Maintenance intervention levels for roads in developing countries should, wherever possible, be determined on an economic basis by using the Highway Design and Maintenance (HDM) (3) or micro-RTIM2 model. Examples of the results of using the micro-RTIM2 model for predicting optimum grading frequencies and regraveling requirements for unpaved roads are shown in Figures 3 and 4. However, for paved roads, the relationship between the rate of pavement deterioration and the level of maintenance is very sensitive to complex variations in the parameters of traffic loading, climate, pavement materials, and so on, and these relationships have still to be quantified adequately. Until such time as the research evidence can provide robust relationships that can be used to predict optimum maintenance levels for paved roads, intervention levels such as those recommended in ORN1 must be used.

ORN1 presents tables of maintenance criteria under the headings of safety, side drains and turnouts, bridges and culverts, road furniture and markings, unpaved roads, paved roads, shoulders, and side slopes. For each element in the table, both the criterion and recommended action are listed, together with a note as to whether the repair is carried out as part of the urgent, routine, recurrent, periodic, or special maintenance program. For the defects of cracking and rutting on paved roads, the criteria for different types of action depend on

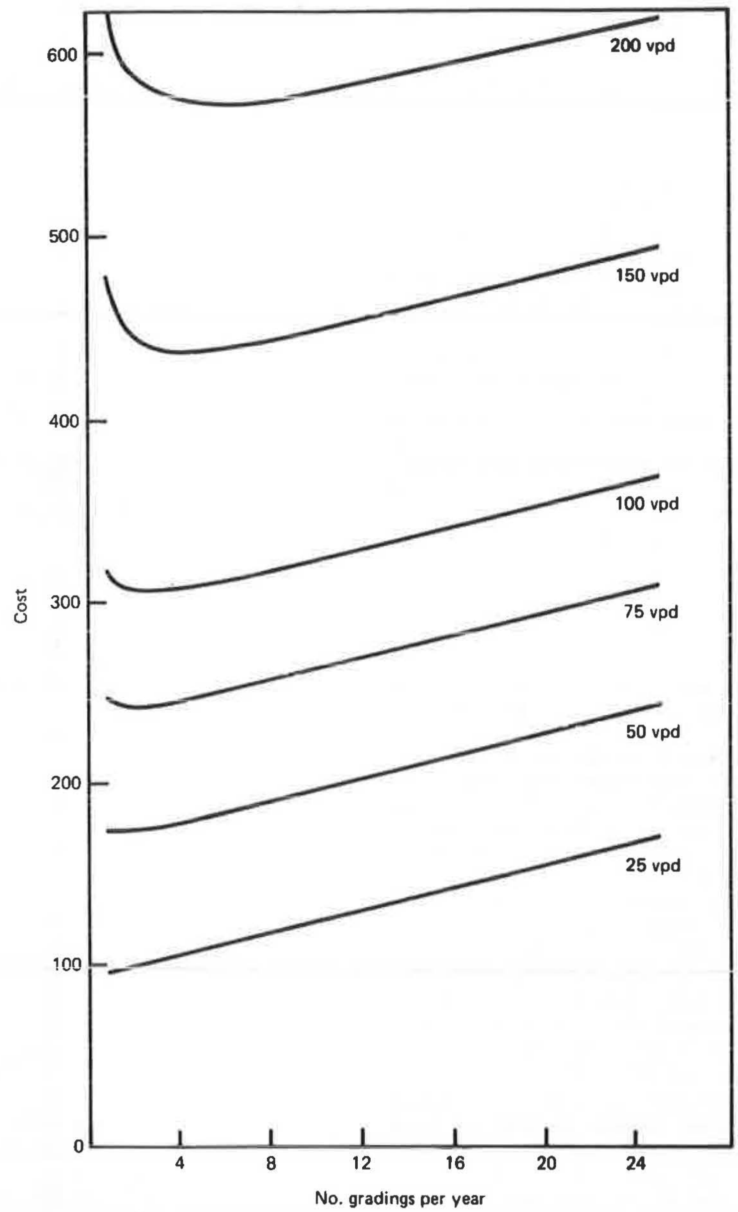

FIGURE 3 Sample plot of maintenance plus road user cost for different grading frequencies.

combinations of defect levels. Although guidance is given on the level of defect at which maintenance is necessary, only general guidance is given about the need for different maintenance treatments where the extent of defects is different within a 200-m length of road. Such an approach simplifies the recording that is necessary in a manual system such as ORN1.

ORN1 and System BSM both recommend that maintenance needs be determined from measurements of the condition of drainage structures, pavement cracking and rutting, and so on, made by inspection teams walking the road. As noted earlier, System BSM utilizes the results of such an inspection to identify where more sophisticated measurements such as those of deflection, dynamic cone penetrometer, and roughness should be made to determine the needs for strengthening and rehabilitation. Furthermore, although exactly the same philosophy of intervention levels is employed with System BSM, because it is a computerized system it is possible to have a range of intervention levels. This enables the user to take account of the relative economic importance of different routes such as could be determined by a road investment model (3). This enables more severe condition constraints to be applied on the more important roads in the network. Similarly, the automatic selection of treatments is relatively simple to arrange on the basis of the information held in the road condition data file. Again printouts are available in a form suitable for rapid checking by a maintenance engineer in the field to ensure that the system decisions are, on the whole, correct (Figure 5).

COSTING

Once the maintenance needs of the network have been identified as a result of the inspection and the application of intervention levels, it is then necessary to determine the resource requirements for carrying out the identified work in terms of men, equipment, and materials.

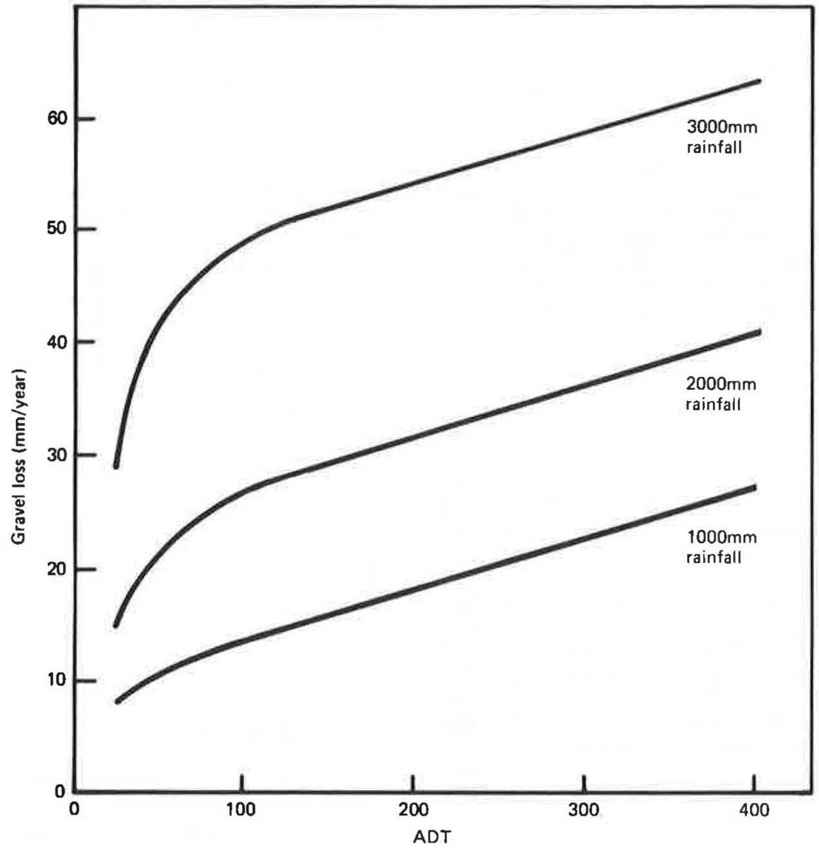

FIGURE 4 Gravel loss.

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                                                                          LEFT        CARRIAGEWAY           RIGHT

                                                                          EDGE_______ RECONSTRUCT__   ______EDGE
                                                                                    I THICK OLAY_ I   I
                                                                          SHLDR____ I REG______ I I   I ____SHLDR
                   P D T C                                                        I I THIN___ I I I   I I
                   R I R N                                                F'WAY__ I I PATCH I I I I   I I __F'WAY
                   O S A S                                                      I I I SD_ I I I I I   I I I
PRTY  REFERENCE    V T F T  DATE                                          LGTH  I I I   I I I I I I   I I I       $
                                                                                I I I   I I I I I I   I I I
6     A0184-001-01 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      243m    X P I             I     R      1712
5     A0184-001-02 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      248m      H I             I     F       653
8     A0184-001-03 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      203m        I X           I            2556
3     A0184-001-04 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      220m        I X           I            2772
18    A0184-001-05 2 2 2 4 11/83 TALIFA RING ROAD - NORTHERN SECTION      192m        I X           I            2418

16    A0184-001-06 2 2 1 4 11/83 TALIFA RING ROAD - NORTHERN SECTION      104m        I     X       I            2556
14    A0184-001-07 2 2 2 4 11/83 TALIFA RING ROAD - NORTHERN SECTION      198m        I X X         I            4793
15    A0184-001-08 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      292m        I   X         I            2170
12    A0184-001-11 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      215m        I     X       I            4644
10    A0184-001-12 2 2 2 1 11/83 TALIFA RING ROAD - NORTHEF SECTION       198m        I         X   I            8906

9     A0184-001-13 2 2 2 1 11/83 TALIFA RING ROAD - NORTHERN SECTION      097m        I         X   I            4362
4     A0184-002-01 2 2 2 5 11/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  381m        I     X       I            7884
2     A0184-002-02 2 2 2 5 11/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  322m        I     X       I            6663
1     A0184-003-01 2 2 3 5 12/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  382m    X   I         X   I           17118
7     A0184-003-02 2 2 3 5 12/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  326m        I           X I           23614

11    A0184-003-03 2 2 3 5 12/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  308m        I     X       I            6375
17    A0184-003-04 2 2 3 5 12/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  310m        I         X   I           13368
13    A0184-003-05 2 2 3 5 12/83 TALIFA RING ROAD - NORTH SECTION (DUAL)  370m        I         X   I           15956
========================================================================================================================
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FIGURE 5 Printout of the abbreviated priority list for 18 subsections in road number order.

In ORN1, guidance is given on resource needs based on tabulated ranges of performance standards for each maintenance activity. A suggestion is also given for a form that can be used to prepare resource requirements and cost estimates for each activity identified on each road.

If unit costs are available, the computerization of the ORN1 method in System BSM allows cost allocations to be made for each subsection where work is required. These costs may vary across a country, and consequently unit rates may be specified for each province of a country for each remedial task that may be used in the system. Thus, cost allocations can be made nationally or for a province or for each district.

PRIORITIES

In the event of a shortfall in budget allocations, both ORN1 and System BSM suggest methods of setting priorities that are objective and depend on the importance of the maintenance activity and the road's being maintained.

ORN1 recommends that priorities be set depending on a cross-classification by traffic and maintenance activity, which is then modified on the basis of local knowledge of soils, topography, and climate. The rate at which the running surface deteriorates and the consequent frequency and extent of lane and shoulder maintenance are closely related to the nature and volume of traffic on the road. A simple road maintenance classification from ORN1 based on traffic is as follows:

Category	Average Daily Traffic (no. of vehicles)	Surface Type
1	Greater than 1,000	Paved
2	500-1,000	Paved
3	200-500	Paved
4	Greater than 200	Unpaved
5	Less than 200	Paved
6	50-200	Unpaved
7	Less than 50	Unpaved

ORN1 also groups maintenance activities by frequency of operation as follows:

1. Routine--likely to be required whatever the engineering characteristics of the road or the density of traffic. They may be considered as fixed-cost activities.
2. Recurrent--may be required at intervals throughout the year, but their frequency varies with traffic.
3. Periodic--required only at intervals of several years.
4. Urgent--unforeseen activities as a result of which the road is cut or becomes impassable.
5. Special--for strengthening and rehabilitation and may be identified as a result of maintenance inspections but should be treated as capital projects whose funding does not come from maintenance sources.

ORN1 recommends that all the identified maintenance tasks be given a priority on a scale of 1 (high) to 35 (low) according to Table 1. This system ensures that a minimum amount of drainage maintenance is carried out on all roads but that funds for recurrent and periodic work are concentrated on the most heavily trafficked roads. When this list of tasks has been prepared, the detailed order of maintenance work in the list should then be changed where necessary by the maintenance engineer to take account of soils, topography, and climate where these are known to affect the maintenance requirement.

TABLE 1 Maintenance Priorities

Task	Priority by Traffic Category 1	2	3	4	5	6	7
Urgent Emergency repairs to cut roads Remove debris Inform police of vehicles that need repair	1	2	3	4	5	6	7
Routine drainage work Clean out and deepen ditches Clean out bridges and culverts Fill scoured areas Build check drains and scour controls Repair structures	8	9	10	11	12	13	14
Recurrent work on pavement Drag, brush, grade, or fill unpaved roads Patch, sand, or locally seal paved roads	15	18	21	24	27	30	33
Periodic work Heavy-grade and regravel unpaved roads Surface-dress paved roads	16	19	22	25	28	31	34
Other routine work Fill on shoulders and slopes Cut grass Clean, repaint, repair, and replace road furniture	17	20	23	26	29	32	35

System BSM assumes that because condition information is generally collected only once each year, the system should only act as a safety net for routine and recurrent maintenance operations. Consequently when, for example, inadequately maintained drainage structures or excessive deterioration of a road surface is observed, a message is sent immediately to remind local maintenance engineers that this task has not been carried out and should be done at the first opportunity. The system concentrates more heavily on periodic and special maintenance. Remedial work falling into these categories is assessed for relative importance in the seeking of maintenance funds as a function of economic importance of the road, the type of defect being remedied, and the extent of that measured defect (2). The system then sorts subsections into an order of priority for their claim on funds and printouts may be obtained showing the extent of remedial work possible with various different resource allocations from central government. This may, of course, be extended to allow a similar exercise at provincial and district levels. By this means, the effect of changes in funding may be rapidly seen or, alternatively, the maintenance engineer is able to respond rationally to an imposed change of policy.

EXECUTION

Neither ORN1 nor System BSM includes scheduling or cost-accounting systems for controlling the execution of maintenance activities themselves. There are many systems available that do this at varying levels of sophistication.

For the manual control of maintenance work, ORN1 recommends the use of a simple all-purpose form on which can be recorded both the work target and the completed production. This enables the engineer to see at a glance whether targets are being met. However, ORN1 places great emphasis on the need for the engineer to make personal field inspections to supervise staff rather than to rely entirely on completed field sheets.

Although System BSM does not include cost accountancy or a work-scheduling package, it is nevertheless self-checking. As soon as maintenance work is completed, reports are made to the system. As each report is made, it is recorded in a data file for the particular subsection and the requirement for the work to be done is cancelled. The road condition record that is used to trigger the demand for work is reset to the "not assessed" state. A comparison of outstanding remedial work with that originally identified by the system will show which areas of the network are being inefficiently operated and appropriate managerial action may then be taken.

MONITORING

The object of monitoring is to ensure that resources are being used in the manner intended and that this use is achieving the desired results. It also provides data that can be used to make adjustments to the operation of the management system in the future. Monitoring normally comprises both field inspections and a desk review of the maintenance reports.

As has been mentioned already, ORN1 stresses the importance of having the maintenance engineer carry out field monitoring himself. It cites the following reasons:

1. To get to know the road network thoroughly, to recognize trouble spots and problem areas, and to form his own assessment of conditions, which can then be used as a base by which the reports submitted by his staff can be judged and will enable him to assess priorities more reliably;
2. To check that the work reported to have been carried out has in fact been done;
3. To check that the quality of workmanship is satisfactory;
4. To discuss practical problems with his staff on site; and
5. To make maintenance gangs realize that the engineer is actively committed to maintenance work, which will be reflected in morale and in the amount and quality of work.

Similarly, ORN1 recommends desk reviews to provide the factual source for

1. Assessing success in achieving the desired results,
2. Checking productivity,
3. Checking costs,
4. Identifying sections that need additional work, and
5. Planning future work.

As noted in the previous section, System BSM does to an extent monitor itself. However, it is still essential that the maintenance engineer be encouraged to check the system regularly and compare information gathered by the system with his own observations of the network. Similarly, decisions made by the system should be checked by the maintenance engineer, so BSM provides outputs, such as Figure 5, to make this monitoring relatively simple. In addition, it is important to be able to study the year-by-year behavior of a subsection in response to treatments selected by the management system in order to plan future maintenance needs and budgeting requirements. This is facilitated by the production of a historical listing, which may be obtained for any group of subsections and which will contain all known information concerning construction, condition, and treatments for the period of system operation. For example, it would be possible to monitor the increase or decrease of the present serviceability index over time to determine whether the intervention levels and priority algorithms have been tuned adequately to ensure that maintenance is being carried out at the optimum level.

DISCUSSION

It may be seen that management systems, whether manual or computerized, may assist the maintenance engineer by providing a rational structure within which to carry out maintenance operations. This necessarily makes maintenance operations easier to control, particularly with the relatively transient staff with which many maintenance units are required to operate. In the final analysis, the success of such systems is largely subjective because they will evolve with the increasing knowledge that earlier variants yielded to operators.

It is to be hoped that following operation of either one or both of the systems in various countries for a reasonable period of time, it will be possible to make a sound judgment on their usefulness. However, as has been noted earlier, it is expected that both will develop and continue to advance with increasing knowledge of road behavior and the interrelationships between road condition and vehicle operating costs.

ACKNOWLEDGMENTS

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National Roads in England: The Code of Practice for Routine Maintenance

JOHN FELLOWS

ABSTRACT

Road maintenance on national roads in England is divided into three general categories--structural, routine, and winter. The operational management of structural and winter maintenance is now well established, mainly because of the high cost and relative importance attached to those areas of activity. Less attention has been paid to the regulation of routine maintenance operations even though the need for consistency across the network is at least as important in this category as it is in the other two. Routine maintenance includes a wide range of different activities, and it was concluded that the best way to achieve a consistent approach would be to produce and implement a code of practice that would set out the procedures for and frequencies of inspections to determine what routine maintenance tasks need to be carried out and, in the case of cyclic operation, the frequency of execution and in some cases the manner in which they are to be performed. The code not only provides a fixed basis for the implementation and management of the work but also, in association with highway inventory data, provides a firm base for the allocation of funds for routine maintenance operations related to need rather than to the financial resources available. The historical background to and the justification for the code of practice are given and its scope, the preparation work involved, its contents, the peripheral management procedures brought into use with the implementation of the code, and the manner in which these relate to the component parts of a maintenance management system are described.

Responsibility for the construction and maintenance of roads in England is divided between central and local government. Central government (through the Department of Transport) is responsible for the national, strategic roads--motorways and all-purpose trunk roads. Local government is responsible for all other public roads.

There are 2260 km of highway in England and 7770 km of all-purpose trunk road. Together they represent only 4 percent of the total road network but provide for about 25 percent of the country's road travel and about 50 percent of all heavy-goods-vehicle movements. The remainder of the network is made up of more than 250 000 km of principal interurban, urban, and local roads, which are the responsibility of 78 local highway authorities. Most of those authorities also act as the Department of Transport's agents for maintaining the national network working under the department's instructions.

About £1.1 billion of public money is spent each year on maintaining the road network. Funds for highways and trunk roads all come from central government, whereas funds for local roads come from local authority resources assisted by central government grants.

Before 1970, maintenance activity had been allowed to develop in a somewhat haphazard fashion with the many highway authorities working to a wide range of standards, if indeed standards were set at all. Certainly, the department tended to concentrate on new construction.

The first major attempt to consider and make recommendations on the planning, execution, and control of highway maintenance in the United Kingdom was made by a committee set up in 1967 under the chairmanship of A.H. Marshall. The report of this committee (1), published in 1970, stressed the importance of assessing the condition of the road network against a set of objective standards, which should indicate what needs to be done and when in order to maintain structural integrity, safety, and amenity with the least expenditure of resources over the life of the road.

The department has a particular problem in the management and maintenance of the national road network in that it is substantially reliant on a large number of individual agent authorities. The individuality and comparative independence of these agents results in a wide divergence in both the rate of spending and in maintenance practices and this is particularly true of cyclic and routine maintenance.

One of the principles of the national road system is to achieve a uniform level of service for the road user. A local authority will make a judgment on the level of service required by the community that it represents and this is often different from that chosen by its neighbor. These differences are not compatible within the context of a national road system, and the department had to make its requirements clear to its agents. With these factors in mind the Secretary of State commissioned Inbucon Management Consultants Limited to carry out a study. Inbucon presented their report (2) in 1982, and three of the main recommendations called for

1. A code of practice for routine maintenance,
2. The setting up of operation reviews by some form of technical audit, and
3. Experimental pilot schemes involving the private sector.

The recommendations were accepted by the department, and work has been proceeding to implement them, with first priority being given to the code of practice.

OVERALL MANAGEMENT OF THE NATIONAL ROAD NETWORK

The department is developing a comprehensive maintenance management system (MMS). It has two parts: structural maintenance management (concerned with replacement and renewal of pavements and other highway infrastructure that have reached the limit of their service life) and routine maintenance management (concerned with work needed to keep partial highway items functioning satisfactorily). The first part is based on the use of structural and visual assessment techniques such as surveys by the deflectograph, the sideways force coefficient routine inspection machine (SCRIM), and computerized highway assessment of ratings and treatments (CHART). The second is based on the inspection and reporting procedures contained within the code of practice for routine maintenance and inventories of highway infrastructure. The whole will integrate with the department's highway database known as the network information system (NIS), which is being developed concurrently with the MMS. Figure 1 shows the relationship.

The maintenance budget for the national road network is some £200 million per year, of which £30 million per year is spent on routine maintenance work. Before the code of practice the allocation of funds for routine work was based on historical outturn costs.

ROUTINE MAINTENANCE OF THE NATIONAL ROAD NETWORK

It is difficult to give a precise definition of what constitutes routine maintenance because of the many and varied operations encompassed by the term. It is easier to define the general objectives of carrying out the work; these are

1. To ensure that the condition of the highway does not become hazardous to highway users or a hindrance to traffic,
2. To ensure that the aids to safety and movements within the highway function satisfactorily,
3. To help preserve the structure of the highway,
4. To protect adjacent land users from injurious damage and nuisance due to the presence and use of the highway, and
5. To protect the environment and preserve amenity.

The stated objectives are not solely confined to routine maintenance.

Table 1 lists operations classified as wholly or partly routine maintenance as related to the stated objectives. This clearly illustrates the value of what has been often regarded as a relatively unimportant part of the highway maintenance effort.

THE CODE OF PRACTICE

A reasonable boundary for routine maintenance can be defined as one between work that has to be carried out to keep a particular highway item functioning satisfactorily and work that is needed to replace the item when normal wear and tear has progressed to the point at which no amount of cleaning, patching, or damage repair will be effective. Table 2 defines this boundary for a number of maintenance examples.

The scope of the code of practice is based on a similar philosophy and deals with the short-term and cyclic maintenance necessary to keep the highway in good working order. It follows that it does not deal with long-term planned replacement or renewal maintenance, although the inspection requirements in the code may point to the need for such maintenance.

The main headings for the code are

1. Inspections for routine maintenance;
2. Minor highway repairs;
3. Footways and cycle tracks;
4. Covers, gratings, frames, and boxes;
5. Curbs, edgings, and preformed channels;
6. Highway drainage;
7. Fences and barriers;
8. Grassed areas;
9. Hedges and trees;
10. Sweeping and cleaning;
11. Road markings;
12. Road studs;
13. Road traffic signs;
14. Traffic signals;
15. Road lighting; and
16. Highway communications installations.

Preparation

The major part of the preparation for the code consisted of a series of fact-finding visits to agent

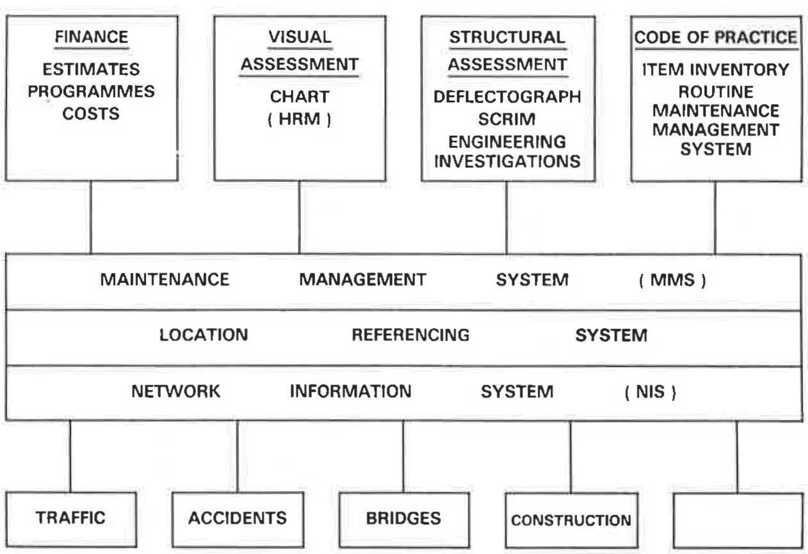

FIGURE 1 Relation between maintenance management system and network information system.

TABLE 1 Routine Maintenance Operations Related to Stated Objectives

	Objective				
Operation	1	2	3	4	5
Verge maintenance (grass cutting, weed control)	*	*	•	*	*
Sweeping and cleaning (highway) and footway sweeping, litter disposal, and debris removal (motorways)	*	•	•	*	*
Highway drainage (gully and drain cleaning, ditch clearance, grips, sewer maintenance)	*	•	*	*	•
Boundary fences, noise barriers, and hedges	*	•	•	*	*
Tree maintenance	*	•	•	*	*
Safety fences and barriers	*	*	•	•	•
Traffic signs (maintenance and cleaning)	*	*	•	•	•
Road markings	*	•	*	•	•
Patching and other minor highway repairs	*	•	*	•	•
Footway maintenance (excluding major reconstruction)	*	•	*	•	•
Ironware on highways and footways	*	•	•	*	•
Curb maintenance	*	•	*	•	•

Note: * = wholly routine maintenance; • = partly routine maintenance.

TABLE 2 Maintenance Boundaries

Maintenance Example	Routine Work	Replacement Work
Reconstruction	-	Complete replacement
Overlay	-	Complete replacement
Resurfacing	-	Complete replacement
Surface dressing	-	Complete replacement
Minor highway repairs	Isolated potholes and dangerous areas	Larger patches over a length of road
Drainage	Isolated repairs to pipes, filter drains, manholes, grips, ditches, etc.	Replacement of lengths of old pipework and filter drains
Footways, etc.	Isolated potholes and other dangerous areas	Large-scale replacement or resurfacing of footways
Safety fences	Repairs of damaged safety fences	Large-scale replacement to accommodate new road levels or when steel work corroded beyond effectiveness
Boundary fences	Repairs of damage caused by stock, vandals, vehicles, etc.	Large-scale replacement of fences at end of useful life of timber
Verge maintenance	Grass cutting, weed control, hedges, and trees	-
Sweeping	Channel sweeping, litter, etc.	-
Drainage cleaning	Gully emptying, grips, ditches, pipe-rodding, etc.	-
Signs	Cleaning, repair, and replacement due to isolated damage	Replacement due to fading and loss of reflectivity (usually on a length of road)
Road markings	Isolated replacement of cat's-eyes and locally worn-out lines	General replacement of worn-out markings

authorities. The intention was to establish the range of existing practice and to find objective evidence justifying its need and measuring its effect.

It soon became apparent that little work had been done to establish the effectiveness, including the cost-effectiveness, of any of the various practices. Generally standards and practices appear to have evolved as a result of financial factors and locally determined priorities rather than through conscious development. Many of the practices were found to be subjective in application and did not point clearly to individual standards that should be adopted. Certainly the variation between the standards and practices of individual agents was often found to be considerable.

Following the investigation, the code was prepared on the basis of the department's own assessment of the standards of routine maintenance that should be applied to the national road network. It will be necessary to monitor the effects of adopting the code over time to determine its appropriateness and cost-effectiveness and to modify it as necessary.

Inspections

Considerable emphasis is placed on the need for formalized inspection systems that use a standard inspection report and action form. Two types of inspection are called for--safety and detailed. The safety inspections are designed to identify those defects likely to cause a danger or serious inconvenience to the public and that therefore require immediate or urgent attention. The detailed inspections are designed primarily to establish programs of routine maintenance tasks and are more activity-specific than safety inspections. Required frequencies for both types of inspections are specified.

Within each area of maintenance activity, defects are defined as either Category 1, which requires urgent or short-term attention, or Category 2, which requires less urgent, longer-term attention. Guidance is given on the scale of defects to be noted and dealt with. Response time requirements for dealing with defects are also given.

Figure 2 shows an operational flowchart for the code.

Monitoring

As explained earlier, the code is at this time imperfect in absolute terms. Also, national standards cannot cover special local requirements. Thus there is provision for controlled variation to fine tune the requirements. The inspection systems will assist in identifying need for both local and national variations. Monitoring is necessary to provide verification of the requirements, and a procedure will be established that will identify where changes need to be made. It is expected that limited revisions will take place from time to time.

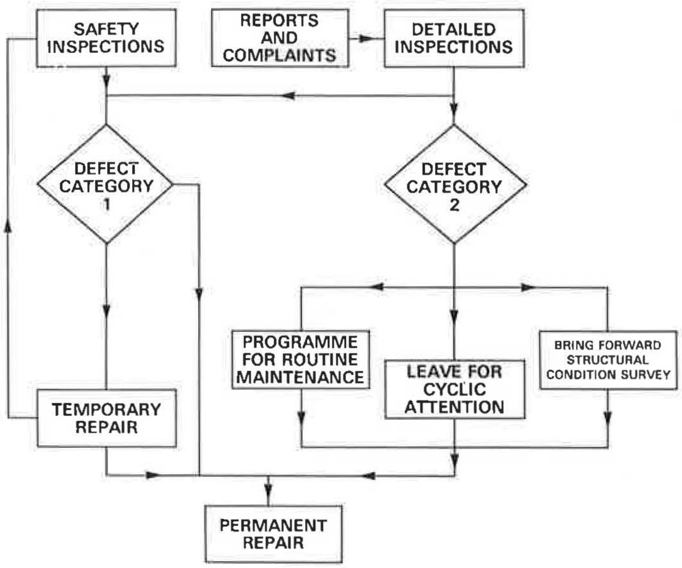

FIGURE 2 Operational flowchart for code of practice.

Application

The code of practice is essentially a working management instruction from the Department of Transport to its agents for the routine maintenance of the national network. The code also provides a firm basis for the allocation of funds and assessment of performance.

IMPLEMENTATION OF THE CODE OF PRACTICE

At an early stage in its production it became clear that the success of the code would depend on the use of efficient and effective arrangements for storage and retrieval of information on the defects, inspection, and remedial action. These arrangements are also the vehicle for translating the policy contained in the code into a detailed working management system.

Information Storage and Retrieval

Before the form of the information storage and retrieval arrangements was considered, it was necessary to define the environment within which these would operate and the objectives to be achieved.

The appropriate environment is considered to be an extension of the existing one by which an agent carries out the management of routine maintenance operations on behalf of the department. Under the code this situation will continue but provision is also needed to make more use of the private sector in carrying out routine maintenance work. In all cases future routine management will be regulated by the code of practice. An assumption was made that, initially, the system would need to be a manual one based on paper files, which, once suitable software became available, could then be computerized.

The objectives to be achieved by the system are to provide checks on compliance with the code; to identify instances in which difficulty is being experienced in meeting the national standards (and thus there is need for local or more general variations to the code requirements); to allow comparisons to be made with other standards, such as those adopted by local authorities; and also generally to provide management information on routine maintenance operations.

The specific requirements of the code also have to be considered, that is, the two different types of inspection (safety and detailed) in 15 different areas of routine maintenance. The manner in which the inspection is initiated needs to be recorded as well as the date, time, and location; the action taken or proposed; and the cost.

Using the Inspection Record

Trained personnel carry out inspections and a single inspection record is completed for each defect found, which is subsequently used to record the action taken and its cost. The form of the inspection record and the requirements of the code impose a discipline and a method of working on the users.

Following inspections the completed records are returned to a central location within the agent's organization for processing. Those responsible for managing routine maintenance programs review this information on a regular basis to determine where action is outstanding and to prepare work programs. By identifying the type of defect and the date of inspection it is possible to determine the time scale within which remedial action must be taken.

Monitoring Performance under the Code of Practice

Agents are setting up systems within their own organizations that comply with the requirements of the code and also the reporting requirements of the department. The department will not have direct access to the actual information but will request performance checks from time to time. These will be for particular problems and more formally under a system of technical audit.

The type of information sought will be the extent to which the code is being adhered to; identification of difficulties in meeting the standards set out in the code; and information on individual defects, the time between inspection, and remedial action.

Spot checks on the systems will be supplemented by inspections on site to check that the work has been carried out satisfactorily.

THE CODE AS A MANAGEMENT TOOL

There are three areas in which the code facilitates and improves management procedures: financial management, performance management, and management information.

Financial Management

In the past the allocation of funds for routine maintenance work on all-purpose trunk roads and highways has been resource led. That is to say, a sum of money was set aside each year within the total amount available for maintenance work, which was largely based on previous outturn costs for routine maintenance. Little or no account was taken of relative performance or the number and type of specific inventory items to be maintained. There is no doubt that across the national road network standards have been uneven. The object of the code of practice is to achieve more uniform standards. This, together with inventory data, will allow the allocations of funds to be made on the basis of need. This should result in a more cost-effective use of resources.

The code identifies in precise terms how much work is to be done and what will be paid for. This ensures that realistic estimates for routine maintenance funds are received from agents.

Inventories are being prepared of the highway infrastructure on national roads in each agent's area and the inspections under the code of practice will be cross-referenced to these. The allocation of funds is to be made on the basis of the inventory and the standards prescribed in the code, taking account of any local variations.

Performance Management

One of the main purposes of introducing a code of practice is to provide some form of control over performance. As already indicated, such control has been limited, with no facility for regulation on a quantifiable basis. The code with the proposed reporting system provides this.

Management Information

The increasing awareness of the public and their greater criticism of the actions of public bodies make it essential to have effective management information systems to be able to deal with complaints. The introduction of the code itself reinforces the need for these systems because it embodies standards that will be used as a basis for judging whether duties have been properly discharged.

The department has commissioned a study to produce suitable software for handling maintenance management information. This will be compatible with the department's network information system.

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Review of Sign Overlay Procedures in Virginia

FRANK D. SHEPARD

ABSTRACT

The sign-refurbishing procedures used by the Virginia Department of Highways and Transportation are discussed with special attention to cost, manpower, time, and quality of the product. In addition, the results of a questionnaire survey made to obtain information on procedures used in other states are presented. Recommendations concerning the most cost-effective and expeditious method of refurbishing signs in Virginia are presented.

Traffic signs are a primary means of warning and guiding motorists, and they must be properly maintained at all times to aid the safe and efficient flow of traffic. Newly fabricated signs have good visibility and legibility; however, the reflective sheeting on the face of the signs deteriorates from exposure to weathering and the accumulation of grime. Once this deterioration reaches the point at which the sign is no longer effective, the sheeting should refurbished or replaced.

Maintaining the large number of signs on the nation's roads demands a substantial effort, especially now that many of the signs erected during construction of the Interstate and urban arterial systems are deteriorating to the point of requiring replacement. Also, refurbishment has to be done under increased traffic flows as a result of increases in travel demand, which causes concern for the safety of both the highway user and the maintenance employee. This concern, coupled with motorist delays resulting from unavailability of sign messages while they are being refurbished, necessitates the use of efficient refurbishment procedures.

In Virginia it was thought to be imperative that an expeditious sign-refurbishing program be established to support the state's efforts to economize without sacrificing safety. Also, it was thought to be important that the refurbished sign be of a quality to assure effective information and guidance for the motorist. In this regard, it should be noted that there has been some concern about possible problems associated with the waviness ("hot spots") of refurbished signs in which overlay panels are used.

Various methods of refurbishing are used in Virginia, including replacement and the application of overlay panels, and each method requires certain manpower, material, equipment, and so on. In view of the foregoing concerns, it was believed that a review of the Virginia Department of Highways and Transportation sign-refurbishing program was timely and would provide information for optimizing the economics and effectiveness of the program.

PURPOSE AND SCOPE

The purpose of this study was to examine the procedures used by the department for refurbishing signs with the intent of recommending improvements. Specifically, information concerning the cost of refurbishment, the time and manpower required, problems encountered, safety, and the quality of the finished product was desired. Also, a survey of other states was made to obtain information concerning their refurbishing procedures.

The investigation was limited to large ground-mounted and overhead guide signs.

PROCEDURE

Information was obtained in Virginia through the use of a questionnaire and from observations of sign-refurbishing projects around the state. Also, a questionnaire was sent to the other states to solicit information on their refurbishing procedures, problems, and so on.

In addition to a study of the methods now used by the department, a new overlaying procedure developed by the 3M Company and designated Grade 9800 System 5 was observed on several of the field projects monitored. System 5 is a high-intensity-grade retroreflective sheeting with a thin, semirigid backing coated with a pressure-sensitive adhesive. This material can be applied over the existing sign in the field.

The questionnaire sent to each of the department's eight districts gathered information on methods of refurbishing and the materials and fabricating process used. Information relating to the refurbishing procedures, manpower, cost, problems, and so on, was obtained through observation of 13 sign-refurbishing projects around the state. Each project was closely monitored from the time the refurbishing process was initiated in the shop until it was completed in the field. Of the projects observed, six involved refurbishing in the field with overlay panels attached with rivets, and one involved attaching overlay panels in the field by using rivets and an adhesive. Five of the projects involved the use of the System 5 procedure for refurbishment. On one project, the entire sign was replaced.

VIRGINIA SURVEY RESULTS

The results are based on data received from the questionnaire sent to each district and from the observation of the shop and field procedures used for the refurbishing projects observed.

Method of Refurbishing

A summary of the elements of the sign-refurbishing procedures used in the Virginia districts is shown in Table 1. All districts use 4-ft aluminum panels for overlaying. These are sized in the shop to fit the sign to be refurbished and are faced with encapsulated lens background sheeting. Five districts use these panels to overlay their signs in place on the highway and attach the overlay panel to the old sign with rivets, two use rivets plus an adhesive, and one either replaces the entire sign or uses riveted overlays. One of the districts that uses an adhesive in addition to the rivets overlays the sign in place in the field, and the other brings the sign into the shop for overlaying. It is noted that two districts are trying the new System 5 method.

Shop Preparation

Riveted Panels

For riveted panels the overlay panels are prepared in the shop by sizing the 4-ft-wide aluminum panels to correspond to the sign to be refurbished and applying the encapsulated lens sheeting. These panels are then either carried to the field for application, which is the procedure used by most districts, or applied in the shop to the old sign, which is brought in from the field. The copy is also applied in the shop by most of the districts, as will be discussed later.

System 5

The only shop time required for the System 5 process is that for cutting and preparing the copy, which is normally applied in the field. Although one district experimented with applying the copy to the System 5 material in the shop, this procedure is not recommended because the sheeting can be damaged by excessive handling (bending, crimping, etc.), which makes it difficult to align and match in the field.

Sign Replacement

For the project on which the sign was replaced, the new sign was fabricated in the shop with directly applied copy, taken to the field, and erected in place of the old sign.

Sign Surface Preparation

Preparation of the sign to be refurbished differs according to the method of overlaying. Initially, the sign is stripped of all demountable copy,

TABLE 1 Elements of District Refurbishment Procedures

	District							
	Bristol	Culpeper	Fredericksburg	Lynchburg	Richmond	Salem	Staunton	Suffolk
Refurbishing procedure								
Overlay on highway								
Rivet in place	X	X		X		X	X	X
Rivet and glue in place					X			
Overlay in shop (rivet and glue)			X					
Replace on highway (erect in place)				X				
System 5		X				X		
Fabrication procedure								
Application of copy								
Direct applied in shop	X	X		X	X		X	
Demountable in field						X		X
Demountable in shop			X					
Aluminum overlay thickness (in.)								
0.040			X	X				
0.063		X			X			X
0.080	X					X	X	
0.125				X				
Panel width (ft)	4	4	4	4	4	4	4	4
Rivet spacing (horizontal/vertical) (in.)	20/20	12/18	–	–	16/8	24/14	8/16	8/8
Crew size								
Shop	2	2	–	7	3-4	2	2	3
Field	3	3-4	–	8	3	3	3	3

rivets, and so on, which would prevent an overlay panel from lying flat on the surface. For signs to be refurbished with riveted overlay panels, the panels are simply aligned and riveted. For signs to be riveted and glued, an adhesive is applied to the overlay panel and sign before attachment.

Figure 1 shows a sign being prepared for the application of System 5 material, which is limited to surfaces that are smooth, clean, and dry. For weathered surfaces that exhibit spalling, ply separation, delamination, or poor adhesion of the paste, all loose material should be removed by scraping and brushing before the System 5 material is applied.

Although instructions for application of System 5 are provided, some uncertainty exists concerning the degree of deterioration (weathering, spalling, ply separation, delamination, etc.) beyond which System 5 should not be applied. Also, because System 5 adheres to the original sign surface, any dents, bends, and so forth, will be visible; therefore, judgment should be used in selecting signs to be refurbished. Nevertheless, many imperfections can be overlaid without any significant problems.

FIGURE 1 Sign preparation for System 5 material.

Overlay Panel Thickness

In Virginia aluminum overlay panels 0.063 and 0.080 in. thick are used for most large guide signs. Panels 0.040 in. thick have been used, especially for smaller signs; however, this thinner material is more difficult to handle and is more susceptible to the formation of hot spots. There are no data for comparison of the 0.063-in. and 0.080-in. panels; however, based on the assumed cost of each material, the 0.080-in. material costs approximately $0.50/ft^2 more than the 0.063-in. material when new ($0.32/ft^2 for recycled material). The prices may vary with individual bids and quantities. Acceptable results are reported in Virginia for both the 0.063-in. and 0.080-in. thicknesses.

As was previously noted, the System 5 material is a thin, semirigid aluminum with an encapsulated lens retroreflective sheeting.

For the project on which the sign was completely replaced, 0.125-in. aluminum was used.

Attachment of Overlay Panels

Riveted Panels

For riveted overlay panels, a rivet spacing of between 8 and 20 in. horizontally and vertically is used; however, rivets are spaced closer along the edges. Sufficient rivets should be placed to secure the sign and minimize waviness, but too many rivets will detract from the appearance. Figure 2 shows an overlay panel being aligned and Figure 3 shows it being riveted. For the projects on which riveted overlay panels were used, no problems were encountered and the panels were aligned and riveted expeditiously.

Riveted and Glued Panels

In the past some districts attached the overlay panels by using only an adhesive, because this method gave a smooth surface. However, problems were encountered when the old sheeting bearing the adhe-

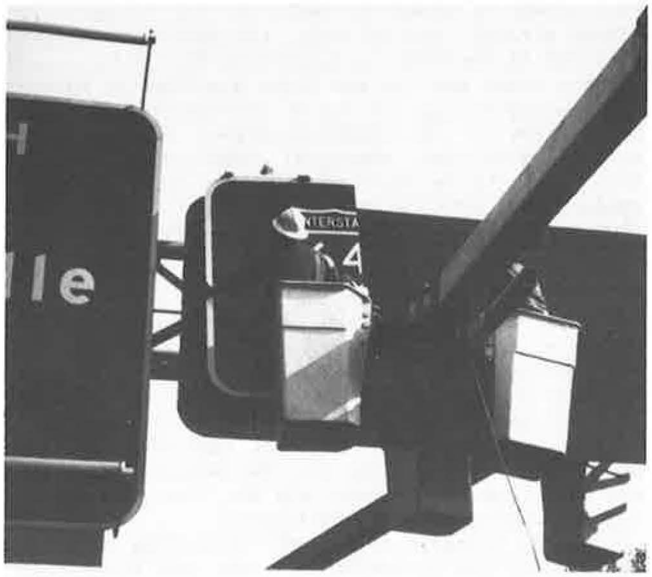

FIGURE 2 Aligning overlay panel on in-place sign.

FIGURE 3 Riveting overlay panel to in-place sign.

sive delaminated and caused the overlay panel to become detached. In an attempt to prevent this situation, rivets were used in addition to the adhesive to secure the panel.

For the refurbishing method employing rivets and an adhesive, the adhesive is uniformly brushed onto the in-place sign and the overlay panel, and the panel is aligned and secured to the sign. Care must be taken when the overlay panel is aligned, because once the adhesive-covered surfaces come in contact, it is very difficult to realign or remove the panel. Also, care must be taken to ensure that the adhesive does not get on the face of the panel and that the cemented surfaces are kept free of dirt, trash, and so on. Using an adhesive in addition to rivets extends the process by requiring extra care in handling and aligning the panels.

System 5 Material

The System 5 material is backed with a pressure-sensitive adhesive and is attached by aligning the 2-ft sheets and pressing them onto the surface with a rubber roller or a soft cloth. No rivets are used in this procedure. Figure 4 shows application of the System 5 sheeting. This procedure requires more field application time than that used for riveted overlays because additional time and care are required in preparing the old sign surfaces and aligning and applying the material. Data on shop and field manpower and time requirements are given later. It should be noted that although it is important to refurbish a sign as quickly as possible, workmanship is also important and special care should be taken in handling and applying the panels. For example, some problems were encountered when the System 5 sheeting wrinkled or captured air bubbles, primarily because the sheeting was improperly crimped or applied. There were also situations in which wind caused problems in application, especially for very high signs.

FIGURE 4 Applying System 5 sheeting.

Application of Copy

Five of the eight districts use directly applied copy for riveted overlay panels; they find that this method is more convenient and cheaper than the alternatives. The directly applied copy is attached in the shop and under favorable conditions, because it can be easily positioned and there is no concern for work-site protection because of traffic. Figure 5 shows copy being aligned in the shop for overlay panels that are to be riveted. Fabricators using demountable copy cite the advantage of being able to change the message without changing the background; others using directly applied copy indicate that changing messages is not a problem. The districts using demountable copy report that the copy is removed from the sign, taken back to the shop, covered with reflective sheeting, brought back to the sign, and reattached. Unless spare letters are available and taken to the field, this process takes more time than using directly applied copy and renders the sign useless for guidance for longer periods of time. In some cases, the sign message may be gone for a day.

For System 5 overlays, the position of the old copy is measured from the old sign and the new copy positioned and applied directly over the System 5 overlay in conformance with these measurements.

FIGURE 5 Shop application of directly applied copy.

Figure 6 shows the application of the copy. It is difficult to get smooth edges when the copy is cut out of the System 5 materials in the shop. With tin snips, two cuttings were sometimes required to get the edges straight and flat. Also, machine pressing, or shearing the copy and border, created a concave area around the edges that made it difficult to get the copy and border to lie uniformly flat on the sign. After approximately 6 months, some deterioration, probably caused by irregular edges, around the edges of the copy and border was noted. Consideration should be given to ways of improving the quality of the copy and border, for example, an improved procedure for cutting in the shop or precut copy and borders.

Shop and Field Manpower Requirements

A summary of the shop and field manpower requirements for the refurbishing projects monitored during

FIGURE 6 Applying copy to System 5 overlay.

this study is shown in Table 2. All projects employed directly applied copy; the System 5 copy was prepared in the shop but applied in the field.

Shop times are the man hours required to prepare the overlay panels for field application, including preparation of the aluminum blanks for the background reflective sheeting, application of the sheeting to the metal blanks (roller and heat application), and application of the copy and border. The shop times did not include any allowance for cutting and preparation of letters, borders, and shields.

Field manpower requirements include man hours for loading and unloading at the shop and in the field, removing copy and border from the in-place sign, preparing the sign surface, and installing the overlay panels. Travel and lane-closure times were not included because they vary according to the sign location and number of signs refurbished per trip.

Table 2 also gives the total time that the sign was out of service, that is, the message was either not visible or incomplete, and the time that maintenance personnel were on the highway.

For the System 5 method of overlaying, shop time is required for preparing the copy and border, but all copy and border are usually applied to the sign in the field.

Figure 7 shows plots of the total man hours (shop and field) required for the methods of sign refurbishment versus the total area of the signs on the projects monitored. Sufficient data were available for the procedures in which the overlay panels were fabricated in the shop with directly applied copy and attached with rivets to the sign in the field and for the application of System 5 material in the field. For riveting and glueing in place and sign replacement, data were available for only one project each. In order to obtain estimates of the man hours for these refurbishing procedures with limited data and different sign sizes, lines were drawn through the single points with assumed slopes identical to those for the riveted overlay projects.

Only two of the available projects were used to establish the curve for the refurbishing procedure in which System 5 material was used. The two were completed by the Culpeper District and represent the last two of six System 5 overlay projects in that district. These projects were used because the System 5 overlaying procedure is new and time was required for the workmen to become familiar with the material and procedures.

In considering the refurbishing procedures normally used by the department, it is obvious from the curves that the method of using riveted overlay panels attached in place requires the least number of man hours for completion. Overlaying in place by using rivets and glue takes significantly more man hours, whereas sign replacement requires substantially more man hours than either overlay method. On the basis of data gathered from the last two System 5 refurbishing projects, this new method requires slightly fewer total man hours than either of the riveting methods.

Crew Size and Equipment

The crew size varies among districts, ranging from two to four persons for shop preparation depending on the method of refurbishing. The crews used in the field for applying both the overlay panels and the System 5 material ranged from three to four men, with the exception of sign replacement, which required more. Unless there are reasons for having a larger work crew, it appears that a three-man crew is appropriate.

Most districts use a bucket truck and a flatbed for refurbishing. These vehicles appear appropriate

TABLE 2 Shop and Field Manpower Requirements for Refurbishment Procedures

Item	Overlay with Rivets by Sign Area (ft^2)						Rivets and Glue[a]	Overlay with System 5 by Sign Area (ft^2)					Replacement[g]
	80	119	138	163	173	224		116[b]	158[c]	109[d]	126[e]	214[f]	
Shop													
No. of men	1.5	-	2	2	2	2	3.5	0	0	0	0	0	7
Man hours	4.1	-	6.9	7.0	7.8	10.1	20.1	0	0	0	0	0	30.8
Field													
No. of men	3	5	4	4	2.5	-	3	5	4	3	3	4	8
Man hours	3.1	6.2	6.0	5.5	5.6	-	13.2	20.3	16.9	17.0	9.9	13.2	23.7
Total man hours	7.2	-	12.9	12.5	13.4	-	33.3	20.3	16.9	17.0	9.9	13.2	54.5
Message unavailable (hr)	0.63	0.97	1.20	-	1.48	-	2.83	3.58	3.75	3.73	2.72	3.88	2.83
Personnel on road (hr)	0.87	1.13	1.38	-	2.03	-	3.15	3.97	4.08	4.13	3.03	4.22	3.17

Note: Dash indicates data not available.
[a]Sign area 213 ft^2.
[b]Project date July 1981.
[c]Project date April 1982.
[d]Project date June 1982.
[e]Project date August 1982.
[f]Project date September 1982.
[g]Sign area 182 ft^2.

for the refurbishing procedure used, with the exception of sign replacement, which may require more vehicles.

Cost of Refurbishing

A cost comparison of the refurbishing procedures is shown in Table 3. In establishing relative costs, sign sizes of 80 ft^2 (small), 140 ft^2 (medium), and 200 ft^2 (large) were used. The total costs do not include those for hand cutting of copy, space rental, or miscellaneous items such as rivets, glue, and tools.

Materials

Costs for materials are those currently being paid by the department for blank aluminum sign material and silver and green encapsulated lens sheeting. The costs of aluminum for the overlay panels were calculated by using costs for recycled aluminum, which is now being used by the department. Also, a salvage value for the overlay panels was included because they can be recycled.

Labor

The labor costs for shop fabrication and field application were estimated by superimposing lines representing the three sizes of signs on Figure 7 and multiplying the resulting total man hours by the hourly wage. Labor costs for travel and work-site protection were calculated by assuming 1.5 hr per day for travel to and from the sites and an assumed 1.0 hr per sign for work-site protection. The cost of labor was taken from the Culpeper District and represents an average hourly rate with additives included.

Vehicle Rental

Vehicle costs were estimated by using the daily rental costs for a bucket truck and a flatbed truck

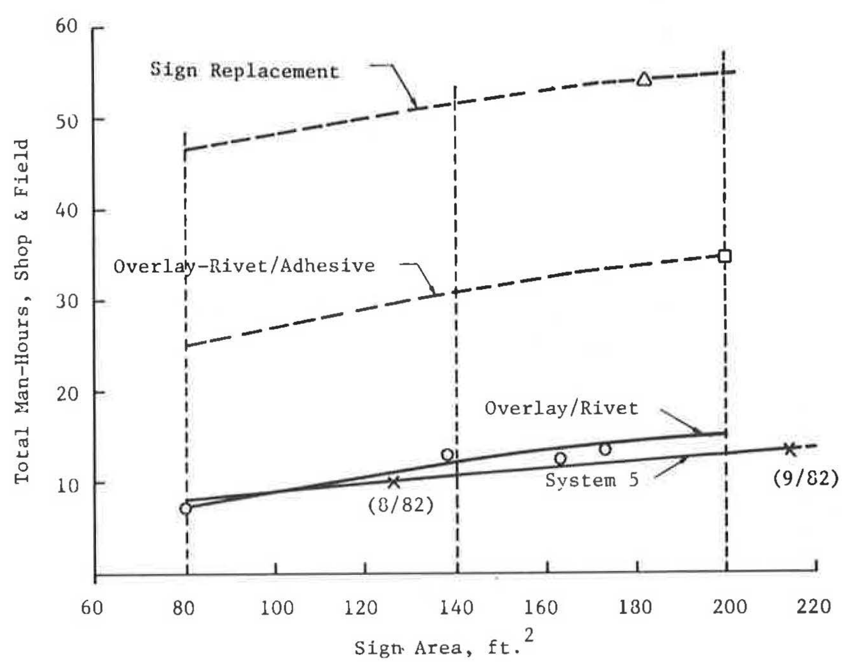

FIGURE 7 Total man hours for refurbishing procedures.

TABLE 3 Cost of Refurbishment Procedures

	Procedure														
	Rivet in Place[a] by Sign Area (ft^2)			Rivet in Place[b] by Sign Area (ft^2)			Rivet and Glue in Place[c] by Sign Area (ft^2)			System 5 by Sign Area (ft^2)			Replace Sign[d] by Sign Area (ft^2)		
Cost ($)	80	140	200	80	140	200	80	140	200	80	140	200	80	140	200
Material															
Aluminum blanks	45	79	113	71	124	177	45	79	113				105	183	262
Reflectorized sheeting															
HI green ($2.94/$ft^2$)	235	412	588	235	412	588	235	412	588				235	412	588
HI silver ($2.94/$ft^2$)	64	111	159	64	111	159	64	111	159				64	111	159
S-5, HI green ($3.65/$ft^2$)										292	511	730			
S-5, HI silver ($3.05/$ft^2$)										66	115	165			
Total material	344	602	860	370	647	924	344	602	860	358	626	895	404	706	1,009
Labor ($9.94/hr)															
Total (shop and field)	72	119	150	72	119	150	249	293	328	81	104	129	463	517	552
Travel and work-site protection (cost per sign)	45	52	75	45	52	75	75	52	75	75	52	75	75	75	75
Total labor	117	171	225	117	171	225	290	363	397	133	179	204	538	592	627
Vehicle rental (per sign)	37	55	110	37	55	110	55	110	110	55	110	110	152	152	152
Total cost of refurbishing	498	828	1,195	524	873	1,259	700	1,080	1,373	546	915	1,209	1,094	1,450	1,788
Total cost per square foot	6.23	5.91	5.98	6.55	6.24	6.30	8.75	7.71	6.87	6.83	6.54	6.05	13.68	10.36	8.94

Note: HI = high intensity; S-5 = System 5.

[a]Sign blank 0.063 in. thick.

[b]Sign blank 0.080 in. thick.

[c]Sign blank 0.063 in. thick.

[d]Sign blank 0.125 in. thick.

in the Culpeper District. This total daily cost was adjusted depending on the number of signs refurbished per day, which resulted in a vehicle cost per sign.

Total

The total cost of refurbishing is given for each sign size and per square foot in Figure 8. Of the procedures normally used for sign refurbishing in Virginia, the most economical method used overlay panels fabricated in the shop with directly applied copy and attached in the field with rivets. The procedure with 0.063-in. aluminum was approximately $0.32/ft² cheaper than that with 0.080-in. material.

The application of overlay panels (0.063 in.) with rivets and glue was more expensive, costing between $0.89 and $2.52/ft² more (depending on sign size) than when rivets alone were used. As might be expected, replacing a sign is significantly more expensive than overlaying.

The cost of using the System 5 material was higher than the riveted-in-place method of refurbishing for small and medium sign sizes, costing approximately $0.61/ft² more than 0.063-in. aluminum

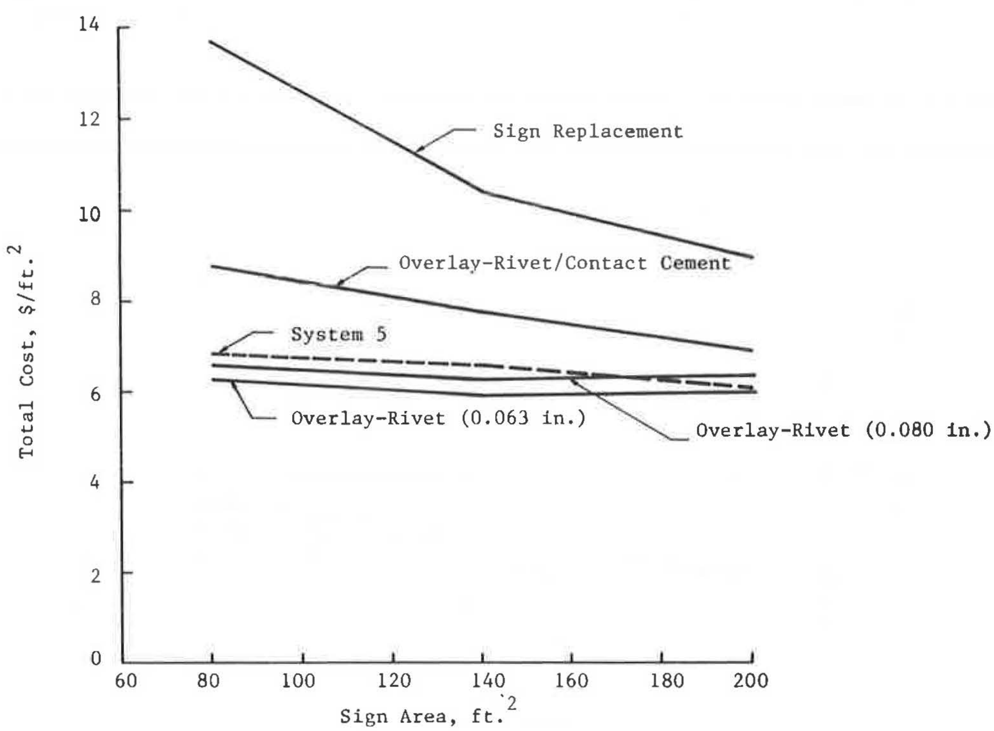

FIGURE 8 Total cost of sign refurbishing.

panels and \$0.29/ft² more than 0.080-in. panels. For large signs, the cost per square foot for System 5 material was approximately equal to that for the 0.063-in. panels and less expensive (\$0.25/ft²) than that for the 0.080-in. panels.

The total cost of sign refurbishing will vary according to the number of signs refurbished per trip, the number of man hours for fabrication and erection, the cost of sheeting, the aluminum sign panel salvage value, and so on. Good planning and the effective use of manpower are therefore important in ensuring an efficient refurbishing program, because many of the costs are fixed.

Exposure to Traffic

The length of time that the sign crew is on the highway refurbishing the sign and exposed to traffic and the length of time that the message is unavailable for guidance are shown in Figure 9. Both of these times are shortest for the riveted overlay with directly applied letters. The other methods require substantially more time, with the System 5 procedure requiring at least twice the time (1.5 to 2 hr) because the message is applied in the field. Although data are not available, use of demountable copy on riveted overlay panels (copy taken to the shop for sheeting application) would take more time on the highway and time during which the message was absent than use of riveted panels with directly applied copy.

In the interest of safety, it is important to minimize the time spent on the road refurbishing signs, especially where there is congestion or high traffic volumes. Also, where the availability for motorist guidance is important, the time required for refurbishing should be kept to a minimum. However, there are areas where these factors are not so critical.

Quality of Refurbished Signs

The relationship between the costs of the refurbishing procedures and the quality of the refurbished sign in terms of durability and legibility has been the subject of a great deal of discussion. For example, it has been noted that use of the most economical procedure, overlaying with aluminum panels, tends to produce signs with wavy surfaces, especially at rivet locations, that cause hot spots at night.

Problems with hot spots caused by wavy overlay panels were acknowledged by personnel in some districts; however, these were not believed to be of great concern. Various opinions were given concerning the cause of sign waviness, especially at the rivet locations. Some theorize that the overlay panel, being thinner than the background sign, tends to react more quickly to temperature variations, and that there is thus a differential in expansion and contraction between the two. Also, some district personnel stated that the thinner aluminum overlay panels presented more problems with hot spots.

At all the district shops visited, it was observed that the new aluminum material used for overlaying was uneven. The material was not uniformly flat; that is, one edge would lie flat on the floor, whereas the opposite edge would be wavy. This unevenness would keep an overlay panel from lying flat against the face of the sign being refurbished.

The unevenness of the aluminum sheeting could decrease the effectiveness of adhesives used for attaching overlay panels. Personnel in one district commented that the adhesive used would not hold after a period of time, and those in another district reported that overlay panels separated from the background sign when the adhesive failed. In light of these problems, and considering the extra cost, time, and inconvenience of using adhesives, the procedure should be questioned.

Overall, the System 5 method produced a refurbished sign of good quality for those installations in which care was taken in applying the material and the sign to be overlaid was in good condition. Periodic observations were made of all the signs refurbished with System 5, and after 1 year most of them were in good condition. One sign showed numerous air bubbles or circular areas in the sheeting. Before refurbishing, numerous rivets were removed from this sign and the old sheeting exhibited spalling. The sign was prepared according to instructions and primed before application of the System 5 material. Close examination of the bubbles revealed that

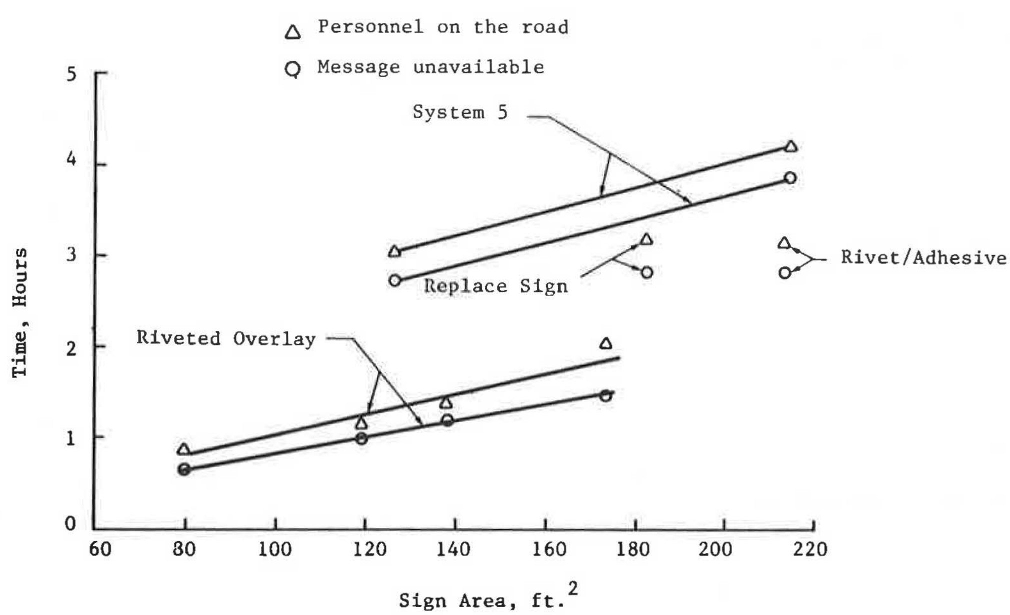

FIGURE 9 Time for personnel on the road and message unavailability.

the problem resulted from a lack of adhesion between the System 5 material and the background panel. In some cases this was caused by small protrusions, especially at the old rivet holes, which prevented the sheeting from adhering uniformly to the back panel. Possible contributions to the problem include entrapment of air during application and entrapment of solvent caused by incomplete drying of the primer, which cannot diffuse through the aluminum. Care should be taken to ensure a smooth surface for the application of System 5. It is difficult to see any entrapped bubbles unless they are viewed at a slight angle from beneath or beside the sign. They cannot be detected at night and do not influence the legibility of the sign. Also, the bubbles do not appear to increase in size.

Data are not available on the long-term durability and visibility of the System 5 material because it is a new product. Therefore, observations will continue to be made.

STATE SURVEY RESULTS

Questionnaires were sent to 49 other states to solicit information on their refurbishment practices and procedures. The general items covered in the questionnaire and the responses are discussed in the following paragraphs.

Method of Refurbishing

About half (51 percent) of the states reported that they refurbish their guide signs by attaching overlay panels in the field, 13 percent replace the sign, and 34 percent either replace the sign or attach overlay panels. The System 5 method of refurbishing is being used experimentally by 47 percent; however, only 2 percent are using System 5 or other commercial overlays exclusively.

Of the signs refurbished, 58 percent are overlaid in place, 16 percent are lowered to the ground, and 7 percent are taken to the shop.

Fabrication of Overlay Panel

Most (94 percent) of the states use aluminum overlay panels with thicknesses varying from 0.032 to 0.080 in. Most overlay panels are either 0.040 or 0.060 in. thick; the thicker panels are generally used for larger signs. Eighty-eight percent of the states reported using the same thickness for all sizes of signs.

Seventy-four percent of the states use 4-ft-wide overlay panels; 77 percent use a butt joint and 14 percent use an overlap joint.

Rivets are commonly used (87 percent of the states) for attaching the overlay panel to the sign backing. Most rivets are either 1/8-in. diameter (48 percent) or 3/16-in. diameter (39 percent) with spacing varying from 6 to 24 in.

Placement of Copy

Directly applied copy is used by 43 percent of the states to refurbish their signs; 30 percent use demountable copy and 23 percent use either directly applied or demountable copy. Four percent use button copy.

Most states (59 percent) apply copy in the shop; however, 21 percent do this in the field. Eighteen percent apply copy both in the shop and in the field, depending on the circumstances.

For those states applying copy in the field, 33 percent measure from drawings, 22 percent measure from the original sign, 19 percent drill through the existing holes, and 15 percent measure from either the drawing or the original sign.

Problems Related to Field Overlay Installations

Fifty-nine percent reported no problems related to work methods and handling of overlay panels, whereas 13 percent noted problems with handling and damage in transport. Thirteen percent indicated problems related to traffic control and equipment use. Seven percent reported problems with wind.

Appearance of Overlay

Generally, there was satisfaction among the states with the final appearance of their overlaid signs; 53 percent reported no problems. Ten of 34 states noted problems with hot spots; however, in 4 states the problems were cited as minor, whereas in 1 the hot spots were blamed on excessive rivet drawdown, and 1 attributed then to prior damage.

The sign overlay materials and procedures used by all states were examined to determine whether the problem with hot spots was associated with overlay panel thickness, rivet size, or rivet spacing. For 0.040-in. material, five states reported hot spots, whereas six had none. Four states had a problem with 0.060-in. to 0.063-in. panels, whereas eight reported no problem. None of the six states using 0.080-in. material reported problems with hot spots or legibility.

There were no apparent influences of either rivet size or rivet spacing.

Criteria for Refurbishing Guide Signs

Seventy-three percent of the states responding have a criterion for determining when guide signs should be refurbished. Of this number, 87 percent inspect the signs, and 13 percent use age as the criterion. Inspection involves day, night, or day and night observation of appearance, visibility, and so on.

Questionnaire Comments

Most comments concerned the procedure for refurbishing included in the foregoing discussion. Some of the more relevant comments are as follows:

1. Aluminum panels 0.040 in. thick were tried (overlapping away from traffic) but it was found that the surface warped or became wavy, perhaps because the thin overlay contracted or expanded at a different rate than that of the original sign background. Now 0.080-in. overlay with 1/8-in. rivets (24 in. vertically and 12 in. horizontally) is used with no problems.
2. The new decade will see much refurbishment of existing signs. The procedure used will depend on which takes the most labor to erect--a new sign or an overlay--plus the cost of materials.
3. There is a saving of approximately 200 percent with overlay as opposed to fabrication of a new sign.
4. Costs have gone up to $\$12/ft^2$, including furnishing and applying new button copy. (Overlay panels were usually attached in field; encapsulated lens with rivets used).
5. All refurbishing is done by contract. Recent

osts are \$12 to \$13/ft², depending on quantity price includes necessary traffic control) compared ith \$15 to \$17/ft² for new extruded aluminum sign panels [encapsulated lens overlay panel (0.040 and .063 in.) riveted in place].

CONCLUSIONS AND RECOMMENDATIONS

Of the procedures used for sign refurbishing in Virginia, overlay panels fabricated in the shop with directly applied copy and attached in the field with rivets is the fastest and most economical. It is believed that this method is an effective and economical means of refurbishing signs and that the department can save a significant amount of money if it adopts the method for use throughout the state and utilizes personnel and equipment as recommended. Little or no surface preparation is necessary and signs can be overlaid in the summer and winter. Also, this procedure requires the least exposure to traffic for maintenance personnel and equipment and also results in the least amount of out-of-service time for the sign.

Although problems with hot spots were acknowledged in some districts, they were not believed to be of great concern. This belief was confirmed by responses to the nationwide questionnaire, which indicated no problems with hot spots.

It is believed that under certain conditions, as noted in this paper, the System 5 method of refurbishing large guide signs is an acceptable alternative. This method, although more expensive, is in the cost range of the riveted-overlay method of refurbishing and, on the basis of a limited observation period, results in a refurbished sign of good quality.

The nationwide questionnaire survey, to which approximately 92 percent of the states responded, showed that slightly more than half of the states refurbish signs by attaching overlay panels in the field and that 13 percent replace the signs. Fifty-eight percent of the signs overlaid in the field were refurbished in place; however, 16 percent were lowered to the ground. Directly applied copy is used more than demountable copy and both are applied in the shop by 59 percent of the states. Most states (94 percent) use aluminum overlay panels of thicknesses ranging from 0.032 to 0.080 in. Most panels are either 0.040 or 0.060 in. thick; the thicker 0.080-in. panels are generally used for larger signs. Rivets are typically used to attach the overlay panels and are usually spaced from 6 to 24 in.

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Evaluation of Bus Maintenance Manpower Utilization

RICHARD W. DRAKE and DOUGLAS W. CARTER

ABSTRACT

Proper manpower planning for transit bus maintenance has not received the same attention as operator manpower planning; yet it is crucial to the economical operation of transit agencies. Maintenance managers have relied on simple ratios such as buses per mechanic or maintenance man hours per mile of operation to perform this function. Recognizing the need for a reliable, relatively uncomplicated maintenance manpower planning technique, NCTRP contracted for this study. Detailed maintenance manpower data were collected from 15 public transit bus agencies that represented a cross section of these agencies in different parts of the country. Consideration was given to the vast differences in the agencies in terms of fleet size, fleet composition, topography, climate, and fleet use. Maintenance manpower requirements were developed on the basis of detailed work activities by vehicle subfleet and functional area. A series of statistical applications were made to compare the range of maintenance requirements and account for variances in time to repair and frequency of repair by vehicle system and subfleet. The manpower utilized by public transit bus operators is reported by vehicle subsystem and by major work activity. This analysis provides the basis for an uncomplicated manpower model that will enable maintenance managers to better plan their manpower requirements on the basis of the specific site criteria of the agency.

Transit agencies have recognized that operator manpower planning is necessary to ensure service reliability and maximum labor efficiency. However, equal attention has not been given to manpower planning for bus maintenance functions. This is in part because maintenance department job assignments often preclude the interchangeability of personnel among functions, skills are often specialized, and the need for maintenance personnel is dependent on many variables relating to equipment and facilities. In addition, multiplicity of work rules and other factors frustrate efforts to apply planning techniques to maintenance manpower. The result is that many transit agencies merely use such simple ratios as buses per mechanic or maintenance man hours per mile of operation as the primary tools for performing this critical function.

Recognizing the need for a more deterministic approach to maintenance manpower planning, NCTRP contracted for the current study, the primary objective of which was to develop a methodology for establishing estimates of labor required for maintaining and servicing diesel transit buses by major vehicle subsystem.

In support of the objective, the research team collected detailed transit maintenance data on times to repair and frequencies of repair by vehicle subsystem at 15 transit agencies. The data were analyzed to determine variances in labor requirements and the impact of independent variables on labor needs. The relationships uncovered in this analysis formed the basis for an uncomplicated maintenance manpower analysis model that is sensitive to local operating characteristics, fleet composition, and other pertinent factors.

This paper summarizes the results of the data analysis activities. The actual manpower estimation technique developed as a result of the analysis is presented in NCTRP Report 10 (1).

AGENCY SELECTION

The objective of this study was to develop a universal tool to estimate maintenance manpower requirements based on an agency's site-specific characteristics; therefore, a representative cross section of bus agencies in different parts of the country was required.

Selection Criteria

Four primary considerations guided agency selection.

Climatic Conditions

The United States has hundreds of localized climates when the specifics of temperature, humidity, wind speed, and sunshine are considered, but when viewed in terms of potential impact on bus maintenance, they can be grouped into major regions with similar winter and summer climatic conditions. Figure 1 shows the different areas:

1. The North-Northeast Region has severe winter conditions with most local areas experiencing biting cold temperatures for much of the winter and moderate summers.
2. The South-Southeast Region is characterized by hot and humid summers with temperatures ranging up to 95° F and mild winters with occasional cold weather.
3. The West-Southwest Region has very moderate winters and a summer climate that is very hot with temperatures frequently in excess of 100° F; however, because this is the arid portion of the country, humidity is very low.
4. In the Northwest Region climate is cool with considerable rain and fog and temperatures are moderate year-round.
5. The Mountain Region climate features low relative humidity and abundant sunshine with cold and stormy winters and mild summers.

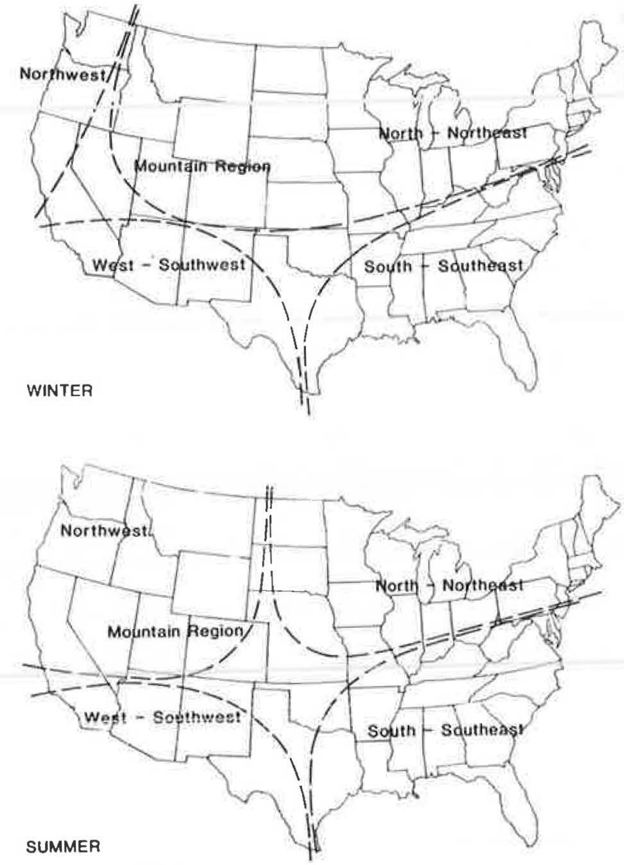

FIGURE 1 Regions with similar climates.

Fleet Size

Fleet size was divided into large (over 1,000 buses), medium (between 250 and 1,000 buses), and small (less than 250 buses).

Terrain

Bus agencies were divided into two categories based on their terrain. Those that operate most of their service over hilly terrain are in one group and all others are in another. Included in the hilly group are those agencies that have a large number of routes with significant changes in elevation over their length.

Data Availability

A most important criterion in the final selection was the availability of required data on manpower use by type of vehicle and by vehicle system. It was not expected that each agency could provide all of the data on every item.

›lected Agencies

ifteen agencies representing a cross section of the haracteristics of bus transit properties were se- ected for the study. An attempt was made to have a arge, medium, and small agency from each of the limatic regions; however, it was not possible to ind agencies in every region that could provide the equired information. Figure 2 shows the geographi- :al distribution of the selected agencies.

1. The North-Northeast Region included the Chicago Transit Authority (CTA), the Southeastern Pennsylvania Transit Authority (SEPTA), the Ann Arbor Transit Authority (AATA), and the Des Moines Metropolitan Transit Authority (DMTA).
2. The South-Southeast Region included the Washington Metropolitan Area Transit Authority (WMATA); the Regional Transit Authority (RTA), New Orleans; and the Austin Transit System (ATS).
3. The West-Southwest Region included the Southern California Rapid Transit District (SCRTD), the Orange County Transit District (OCTD), and the Albuquerque Transit System (ATS).
4. The Northwest Region included Seattle Metro (Metro); Tri-County Metropolitan Transportation District (Tri-Met), Oregon; and Salem Area Mass Transit District (SAMTD).
5. The Mountain Region included the Regional Transportation District (RTD), Denver, and the Utah Transit Authority (UTA).

FIGURE 2 Geographical distribution of selected agencies.

DATA COLLECTION

A plan was developed to define the data required for the study and the techniques to be used to collect maintenance manpower data from the selected bus agencies. The major elements of the plan included

1. A listing of vehicle subsystems for which maintenance manpower data were gathered,
2. Site-specific criteria that were anticipated to influence maintenance manpower, and
3. The data collection guide to be used to capture required information, including a standard glossary of terms to ensure consistency of collected data.

Vehicle Subsystem Identification

For the most part, public transit agencies around the country do not use a common breakdown of major vehicle subsystems in their maintenance reporting systems. A listing was developed for this project and was coordinated with the agencies before it was made final. Most of the suggested changes were accommodated and the final listing is as follows:

- Air
- Air conditioning
- Body
- Drivetrain
- Electrical
- Engine and fuel
- Heating and ventilation
- Steering
- Suspension
- Wheels and tires
- Vehicle accessories
- Destination signs
- Fareboxes
- Wheelchair lifts

Site-Specific Criteria

In planning its maintenance manpower requirements, each public agency is influenced by many local factors. The factors that were anticipated to have a measurable impact and selected for this study are discussed in the following paragraphs.

Climate

The climate was expected to have a significant effect on the manpower required to maintain air-conditioning equipment in the hot regions of the country and heating equipment in those areas that experience harsh winters. In addition, hot engines are reported to be a major contributor to road calls in the regions that have hot summers and the high engine temperatures may also reduce engine life, which would result in more frequent engine overhauls.

Terrain

Agencies that operate service in hilly terrain must perform more frequent brake adjustments than those in flat terrain. Brake life may also be affected. Other areas may not be considered to be hilly but have numerous bus routes that have gentle changes in elevation of several hundred feet over the length of the routes.

Fleet Composition

Public agencies are required to have many different types of buses in their fleet to satisfy different service requirements. These may include 30- to 35-ft buses for circulator service, 40-ft standard coaches for local line-haul as well as express service, and 55- to 60-ft articulated buses for heavily patronized local and express routes. With competitive bidding procedures in place throughout the country, an agency may also have buses of each type from several manufacturers. Each has unique maintenance requirements that must be considered in manpower planning.

Fleet Age

As vehicles accumulate service miles and hours, their maintenance requirements may increase. If so, more manpower must be devoted to older buses in order to maintain their availability and reliability through aggressive preventive maintenance programs and replacement or repair of worn or failed components.

Operating Speed

The average operating speed in revenue service was used as the determining factor to learn whether buses require more maintenance when operating at low average speeds than at higher speeds.

Work Rules

Work rules may have a significant impact on maintenance manpower. Nonproductive time for such items as coffee breaks and cleanup time may be as high as 15 percent of the work day at some agencies.

Local Policies

Local policies are a significant factor in determining maintenance manpower. These were reviewed at each agency to determine their impact. For example, manpower devoted to maintaining wheelchair lifts may be directly related to availability and deployment policies.

Some agencies require that all body damage be repaired immediately, whereas others schedule buses through the body shop periodically to repair accumulated dents and paint scratches. In addition, the policy on level of cleanliness may be reflected in man hours devoted to major cleaning activities.

Data Collection Guide

A well-structured data collection guide was considered mandatory for a study involving quantitative data analysis to ensure consistency in data collection. The guide was structured to capture both quantitative information such as time-to-repair estimates for selected jobs and agency descriptive information as well as qualitative information that was needed to interpret the results of analysis. The data collection guide was organized into six sections.

General Agency Information

General information that described the selected agency and its operating characteristics included

- Total annual miles operated
- Revenue service miles
- Revenue service hours
- Peak-period requirements
- Base-period requirements
- Active bus fleet
- Spare buses
- Weekend service requirements
- Facility information
- Vehicle accident statistics
- Road calls
- Wheelchair lift policy

Maintenance Staffing Information

Details on maintenance staffing for the agency were obtained for the different levels of supervision as well as direct maintenance personnel. Organizational characteristics of the agency were determined to understand differences between agencies, in particular the role of mechanics as supervisors.

Manpower Utilization Data

Information to determine the nonproductive time at each agency was gathered. Vacations, sick leave, holidays, overtime, time off, and paid nonproductive time were addressed. These items can have a signif cant impact on total manpower levels.

Bus Subfleet Data

Information was obtained that described each vehicl subfleet. Details on the major vehicle component were included.

Vehicle Systems Data

Repair times and frequencies for each vehicle subsystem presented earlier were collected for eacl subfleet. The information was divided into runninc repair (light maintenance) and unit repair (heavy maintenance).

Standard Glossary of Terms

A clear understanding of these terms by the members of the research team was important. Before scheduled visits, the glossary was mailed to each of the selected agencies for comment. During the on-site interviews, the terms were discussed in relation to the collected data to determine whether there were any differences that needed to be considered during the data analysis.

Data Collection Procedure

Actual data collected using the guide were handled by visits to each agency by a member of the study team. Well in advance of these visits, the data collection guide was mailed to each selected agency and discussed by telephone. Each agency was asked to compile as much information as possible before the visit so that the time on site could be devoted to understanding the information and to making key field observations that would be useful in interpreting data during the analysis. It was very important to capture the agency's maintenance philosophy and understand its maintenance reporting system.

ANALYTICAL APPROACH

The analytical approach for compiling and evaluating the maintenance manpower data collected from the selected bus agencies was composed of three primary elements, discussed in the following paragraphs.

Develop Manpower Requirements

The technique for developing maintenance manpower requirements viewed maintenance activities as a production function. Many maintenance activities are routine in nature and the amount of man hours required to perform the tasks is identifiable with a reasonable degree of accuracy. The technique relied on the collection of disaggregate data (e.g., maintenance task, job times, and frequency by subfleet). The manpower development technique was made up of four key steps:

1. Line work-hour requirements were estimated separately for four maintenance functions--inspections, component rebuild and heavy repair, running repair, and cleaning and servicing;
2. Work-hour requirements were expanded by scheduled and unscheduled labor hours unavailable for work;

3. Line staff hours were reduced by overtime ıours to determine total regular man hours; and

4. The estimate of regular man hours was comɔared with the actual figure and all differences vere reconciled.

Determine Line Work-Hour Requirements

Line work-hour requirements were estimated at a disaggregate level (e.g., maintenance task by subfleet) for each functional area. Line work-hour requirements represented those hours spent performing maintenance tasks that could be accounted for by a transit agency. Hour estimation was conceptually similar for each function with job times and frequency driving labor-hour needs. However, the functions did vary somewhat and are discussed as follows:

1. Inspections: Maintenance inspections are routine in nature and are relatively easy to schedule and monitor. The time to perform each type of inspection was easy to estimate because of its repetitive and routine nature. Only hours spent on inspection were included in this calculation. Frequently scheduled inspections included time for light repair work. Hours spent on this activity were included in running-repair estimates. Total annual inspection hours was found by summing hours for all inspection types across all subfleets.
2. Component rebuild and heavy repair: The unit rebuild function was also characterized by routine activities that are relatively straightforward to schedule and analyze. Labor hours expended on rebuilds was estimated by obtaining average times to rebuild major components and the average life of the component experienced by the agency. Some agencies included removal and replacement time in the component-rebuild totals; however, this work activity was placed under running repair and not included in this part of the analysis.
3. Running repair: Estimation of work hours expended on running-repair or light-repair activities required three primary calculations. First, running-repair time expended during inspections was estimated by determining the average time spent on repairs during each inspection and the total inspections performed. Second, running-repair time spent on removal and replacement of major vehicle components was estimated by obtaining the average time for each type of replacement and the frequency of exchange for the component. Third, all other running-repair time was estimated by obtaining the average time spent on the other repairs during each year.
4. Cleaning and servicing: Cleaning and servicing of revenue vehicles was usually a routine activity that was easy to evaluate. Number of vehicles serviced daily was determined by using the average number of vehicles dispatched on weekdays, Saturdays, and Sundays, and the number of days that each of these schedules operated during the year. The average time required to take a bus through the complete servicing and cleaning cycle was estimated. Major cleaning activities generally occurred on a regular, although less frequent, basis. The number of vehicles cleaned was estimated by using the active fleet size and the number of cleanings per vehicle per year.

Expand Work Hours

Total hours spent on work activities was expanded by scheduled and unscheduled labor hours unavailable for work. Scheduled unavailable time included vacations, holidays, paid lunch or coffee breaks or both, scheduled clean-up time, and so forth. Unscheduled time unavailable included sick leave, worker's compensation, jury duty, union activities, and other unanticipated demands on total worker hours. Although these hours did not contribute to the conduct of maintenance activities, they did expand the size of the staff needed to perform maintenance activities.

Reduce Expanded Hours by Overtime

The previous steps resulted in an increased need for maintenance employees. Overtime has the opposite effect. It actually reduces the number of employees needed to perform work activities (i.e., each mechanic works more hours). Subtracting overtime hours from the expanded hours resulted in regular maintenance man hours.

Compare and Reconcile Line Hours

The build-up of regular line staff hours was compared with the actual man hours for maintenance line staff. Actual man hours were determined by multiplying total staff by 2,080 hr per year. The estimated and actual maintenance hours were then compared to identify discrepancies. Every reasonable effort was made to identify reasons behind the differences and attempt to mitigate discrepancies. Initially, the primary means of investigation was to continue the interview process, focusing on potential areas of unreported work. The team compared results from the agencies to help identify potential causes of the problem, and if a particular work activity or entire functional area appeared out of line, it was compared with one from a similar system.

Several areas were investigated. At some agencies master mechanics are used as supervisors on late and weekend shifts. These hours had to be removed from the actual figure and added under supervision. Another area was small unreported jobs (e.g., valve rebuilding in component rebuild) that in the aggregate accounted for a significant amount of man hours. Unproductive time was also a contributing factor. These problems had to be identified, where possible, and the time included in the estimated figure. This required going back through the previous estimation steps.

If a difference still existed between the estimate and the actual figure, the amount was handled as a lump sum representing other unaccounted hours and the estimate adjusted accordingly. The normalized hours could then be divided by 2,080 to yield manpower requirements.

Make Comparative Analysis of Results

After manpower requirements had been developed at each of the individual transit agencies, the study team conducted a comparative analysis of maintenance manpower data collected and the ensuing results. The comparative analysis was designed to identify the range of variables reported by the subject agencies. The comparisons were conducted at the subfleet level by vehicle system and included job performance and frequency parameters. In addition, aggregate manpower requirements (e.g., proportion of labor resources by function, unavailable time, and overtime) were compared. The primary tools of comparison were the mean and standard deviation (using n - 1 weighting to account for the limited sample size). The most efficient means of analysis was via a spreadsheet program on a microprocessor.

Evaluate Impact of Independent Factors

Because this research activity was unique, there was no past experience that would suggest probable outcomes of the comparative analysis. Based on the results of the comparative analysis, the study team applied simple and multiple regression analysis and the coefficient of correlation (r) to identify causal factors contributing to the variation in manpower needs between agencies. Both of these techniques are common statistical methods and are not discussed further here.

LIMITATIONS OF MANPOWER REPORTING SYSTEMS

It was found that maintenance reporting systems are in a state of rapid transition from manual cost-reporting systems to automated maintenance management systems. Maintenance programs are rapidly entering the age of computerization. Although this change has been under way for a number of years, the pace has quickened and many of the industry leaders reported that their systems became operational only during the past 2 years and that development of all system elements is not yet complete. The low cost of microprocessors has opened this option to the small operator.

All transit agencies that were surveyed are in some stage in the process of developing computerized systems, and some have joined in cooperative efforts. The leaders in these efforts have in place on-line, interactive systems that can provide individual bus histories to mechanics on the work floor. Efforts are under way to include unit repair functions with the capability to trace the units back to specific buses or bus types. With the ability to capture detailed information on all work tasks, several agencies are in the process of developing work standards based on actual work histories to be used in their manpower planning.

Of the 50 agencies contacted to participate in the study, only 15 reported that their reporting systems could generate data of the type needed for the study and none could provide all of it. The major deficiency was the inability to report information by subsystem and by type of vehicle. Most agencies could summarize manpower by system (e.g., manpower used on engines repairs) but not by vehicle subfleet.

Another major deficiency was the reporting of manpower used in unit repair functions. Almost every agency had good information on the time to overhaul the different components and the number of units overhauled in any reporting period but few could relate this information to a specific vehicle subfleet. Several agencies could report the average number of miles on each major component in the operating fleet but did not have information on components at failure. This important data element was obtained in most instances through inventory control records that documented the number of units issued to buses.

Many of the maintenance management systems were oriented during their development toward cost accumulation and reporting. Although these were excellent for their intended purpose, they were not able to produce information for this study. Some agencies with a national reputation for excellence in maintenance and stated willingness to participate were not included for this reason.

MANPOWER REPORTED

Maintenance personnel shown in transit agency budget and organization charts were found to have many wor assignments in addition to maintaining and servicin transit vehicles. Before the accuracy with which eacl agency could account for its manpower could be eval uated, these different work assignments had to be identified and manpower requirements adjusted ir order to determine the manpower devoted to the diese transit buses under review.

Cleaning and Servicing

Cleaning and servicing personnel had many varied assignments. At some agencies these personnel performed routine janitorial services in addition to their normal assignments, whereas at others separate groups carried out this work. Cleaning and servicing personnel were also used for snow removal in the winter and lawn care in the summer. Many performed clerical duties in assigning bus parking and initiating work orders from bus defect reports received from bus operators.

The small agencies were able to account for more than 92 percent of their servicing and cleaning manpower because the work crews are smaller and easier to supervise. In addition, the time to circulate buses through the cleaning-servicing cycle was better known in the single-facility agencies.

Medium-sized and large agencies accounted for 82 and 83 percent of their servicing and cleaning man hours, respectively. These numbers are considered to be quite good because they are based in large part on an average time to take a bus through the servicing and cleaning cycle at a single facility. The number of bus maintenance facilities at these agencies varied from as few as 3 to as many as 12. Each had different circulation and parking arrangements with varying time requirements.

Maintenance

In addition to work on the transit buses, maintenance personnel perform repairs and routine maintenance on a wide variety of other vehicles, including support vehicles and staff cars. Personnel were also dedicated to specialized vehicles that ranged from electric trolley buses to trolley cars, paratransit vans, and specially equipped vehicles for handicapped passengers. All maintenance organizations reported some manpower spent on building maintenance; however, the larger agencies tended to have separate organizations responsible for the majority of this type of work.

The small agencies accounted for 100 percent of their maintenance manpower. Again, the staffs are closely supervised and accountability of time is easier to achieve. A single mechanic represents a significant percentage of total man hours, so any unreported time is easily detected and quickly adjusted.

Medium-sized and large agencies accounted for 78 and 75 percent of their maintenance time, respectively. Most maintenance managers and supervisors stated that the primary contributor to unreported time was the movement of buses to and from the repair bays. Mechanics report only time spent on actual repairs and few agencies had a way for them to record their unproductive time in bringing a bus into their work area.

anpower Distribution

verall the agencies accounted for an average 82 ercent of their available manpower. The distribu- ion of the manpower as estimated by function and ubsystem is shown in Table 1. The manpower vari- nces and independent factors driving those vari- nces are detailed in the following section.

ANPOWER VARIANCES

Taken at a disaggregate level, the manpower require- ments for maintaining revenue vehicles varied con- siderably among the transit agencies investigated in this research program. However, when the analysis is made at an aggregate level, causal factors driving the manpower differences become apparent, and labor requirements become congruous. This section presents the results of the research into manpower variances by maintenance function and subsystem.

The primary tools used to identify causal factors included correlation, regression, factor impact, and standard error analyses. Once a significant rela- tionship between the manpower requirements and an independent variable had been identified, the mean and standard deviation (using n - 1 weighting to account for the constrained sample size) of the relationship were determined.

TABLE 1 Distribution of Manpower

Work Function or Subsystem	Percent of Manpower
Servicing and cleaning	21
Body repairs	21
Inspections	12
Engine and fuel	9
Braking	7
Electrical subsystem	6
Air, steering, and suspension	5
Air conditioning, heating, and ventilation	5
Drivetrain	5
Accessories	5
Cooling	3
Wheels and tires	1

Cleaning and Servicing

The amount of man hours spent on cleaning and ser- vicing is a function of the amount of time required to perform each activity and the number of vehicles cleaned and serviced. In most of the agencies sur- veyed there are three primary activities for cleaning and servicing staff: daily servicing, major interior cleaning, and chassis wash. Of the three, daily ser- vicing accounts for the majority of staff time. On the average, cleaning and servicing accounted for 21 percent of maintenance man hours; the range was from a low of 5,600 man-hr to a high of 262,350 man-hr per year. The primary factor driving the difference in man hours is the scale of operations, expressed as the agency's peak-hour number of vehicles.

The coefficient of correlation between peak-hour vehicles and man hours for cleaning and servicing was 87 percent, leaving a standard error of 13 per- cent. The additional variation in man hours was attributed to policy differences in the frequency of cleaning activities (particularly between major interior cleanings, which ranged from biweekly to once every 3 months) and the relative efficiency of facilities.

On the average, the agencies surveyed required 138.5 man-hr per peak-hour vehicle per year for servicing and cleaning, as shown in Figure 3. The standard deviation was ±19.9 hr per peak vehicle; the difference was primarily attributable to the physical layout of servicing facilities and the frequency of major interior cleanings. For example, one agency's servicing facility was not originally designed for this purpose and required that vehicles drive through three buildings, each separated by a public street, during the daily servicing cycle. This extended the time required to perform a daily servicing and placed the agency in the upper range of manpower requirements. Similarly, most agencies surveyed conduct a major interior cleaning on every active vehicle once a month. One agency conducted major interior cleanings only once every 3 months, and subsequently appeared in the lower range of work-hour requirements.

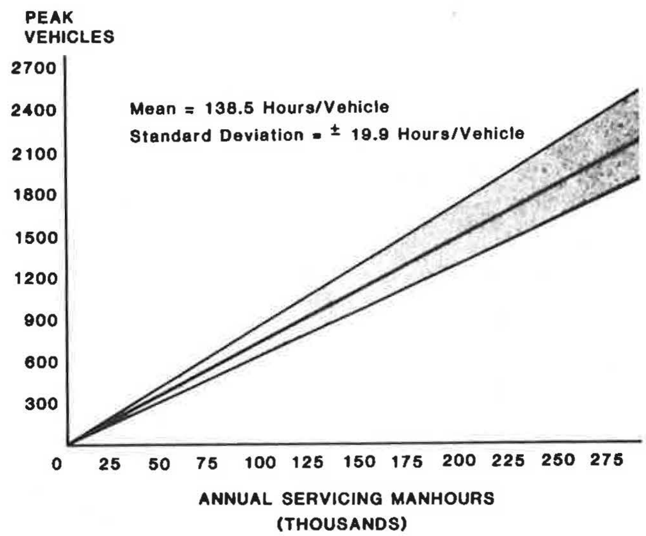

FIGURE 3 Servicing and cleaning man hours.

Body

The body subsystem is composed of running repair and major repair to body, painting, upholstery, and glass. On the average, the body subsystem accounted for 21 percent of total man hours. Total annual body man hours ranged from 1,800 to 365,750 man-hr per year in the study group. The amount of man hours devoted to body repair is a function of vehicle miles (i.e., exposure), accident rates, and policy regarding acceptable vehicle appearance.

The coefficient of correlation between vehicle miles and man hours required for body repair was 65 percent, leaving a standard error of 35 percent. Because of the low correlation, body man hours was investigated further. Accidents were identified as another significant factor driving body man-hour requirements. Together, vehicle miles and accidents account for 91 percent of the variation in man hours, leaving a standard error of only 9 percent. This remainder may be attributable to policy regard- ing acceptable vehicle appearance (e.g., painting frequency) and campaigns to improve vehicle ap- pearance.

On the average, the survey agencies required 219 man-hr for body repair per 100,000 miles, as shown in Figure 4. The standard deviation was ±76.5 hr per 100,000 miles. The survey agencies also had an

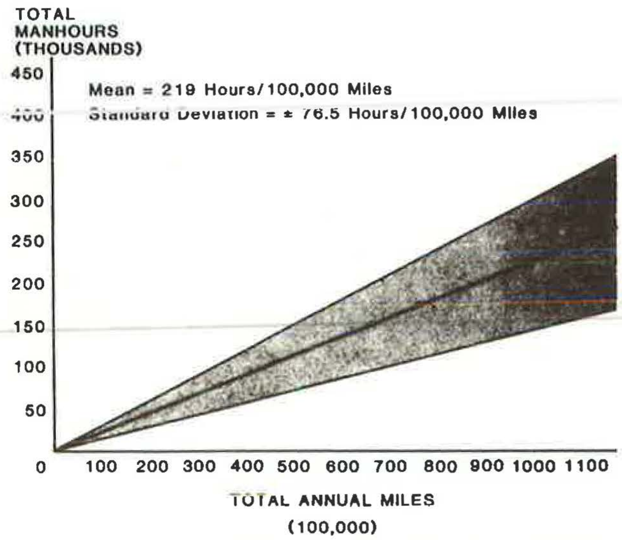

FIGURE 4 Body man hours.

average of 40 accidents per 1,000,000 miles. Manhour requirements per 100,000 miles for body repair were lower for agencies with lower accident rates and higher for agencies incurring accidents more frequently. On the average, agencies required 5.5 hr per 100,000 miles for body repair for each accident per 1,000,000 miles, as shown in Figure 5. An agency with 40 accidents per 1,000,000 miles would be expected to require an average of 219 man-hr per 100,000 miles. There was a standard deviation of ±1.5 hr per 100,000 miles for every accident per 1,000,000 miles. This deviation is primarily attributable to local policy. An agency with a high priority on vehicle appearance would fall in the upper range (e.g., 7.0 hr per 100,000 vehicle miles), whereas a system with a lower emphasis on body appearance would fall into the lower range (e.g., 4.0 hr per 100,000 vehicle miles).

Inspection

The inspection function generally consists of some type of inspection (e.g., safety, minor, major, and statutory) and some amount of repair time, which is included in each inspection. In the survey group, annual inspection time ranged from 2,900 to 166,00 man-hr. On the average, inspections accounted for 1 percent of total maintenance manpower but varie significantly by transit agency. The primary reaso for differences in this manpower category is loca maintenance philosophy regarding inspection.

The coefficient of correlation between inspectior man hours and vehicle miles was only 20 percent, leaving a standard error of 80 percent. Similarly, low correlations were found between inspection frequencies and manpower requirements. No independent variable, or group of variables, was identified as having a significant effect on inspection hours. Some agencies have time-consuming statutory inspections although most have none. Some agencies have several types of safety inspections, whereas others use only minor and major inspections. Further, some agencies devoted 50 percent of inspection time to running repair, whereas others allowed no running repair during inspections.

On the average, agencies required 240 man-hr per 100,000 miles for inspection, as shown in Figure 6. The standard deviation was ±192 man-hr per 100,000 miles. Agencies with a high number of hours for this function generally had statutory inspections to contend with or focused on inspection as a means to meet repair requirements before failures occurred. Agencies with a low number of hours generally had fewer inspection types or excluded most running repairs from inspection or both.

Engine and Fuel

Initially the research team attempted to evaluate engine and fuel repair separately. This proved impractical, because many of the subject agencies combined these functions into one subsystem for internal records. The engine and fuel subsystem as analyzed in this study is made up of repair, removal and replacement, and rebuild times for all engine and fuel system components.

Engine and fuel man hours accounted for an average of 9 percent of maintenance man hours and ranged from 2,460 to 191,200 man-hr in the survey group. The primary difference in man hours was attributable to miles of operation, with vehicle type playing a significant role.

The coefficient of correlation between engine and fuel man hours and vehicle miles is 76 percent,

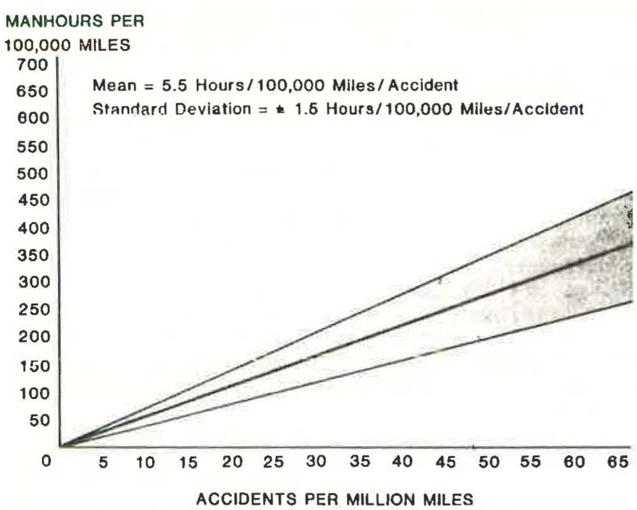

FIGURE 5 Effect of accident rate on body man hours.

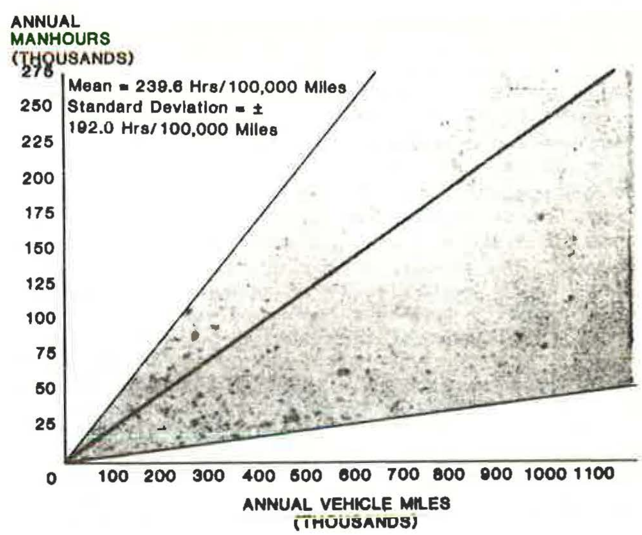

FIGURE 6 Inspection man hours.

eaving 24 percent of the variance not accounted for y miles. Other factors were investigated, including average speed, fleet age, and miles per bus per year, with no significant correlation found. Finally, an investigation of engine and fuel man hours per 100,000 miles by vehicle type produced a significant correlation, bringing the total correlation for these two variables up to 95 percent. The remaining 5 percent standard error may be the result of a number of factors, including mechanic training, facility efficiency, and contracting provisions.

On the average, the survey agencies expanded 157 man-hr per 100,000 miles on engine and fuel maintenance, as shown in Figure 7. The standard deviation was ±38.4 hr per 100,000 miles. Most of this deviation was attributable to the fleet mix, as shown in Figure 8. Depending on the vehicle accumulating miles, engine and fuel man hours ranged from a mean of 130 [e.g., General Motors Corporation (GMC)] to 229 (e.g., M.A.N. Truck and Bus Corporation) per 100,000 miles. On the average, subfleet standard error from the mean was 30 percent. Interestingly, the two outliers in terms of standard deviation [Grumman Flxible Corporation (GFC) with ±10 hr, and M.A.N. with ±135 hr] each had the smallest sample size--four agencies each. The remaining subfleets had between 8 and 12 survey agencies each.

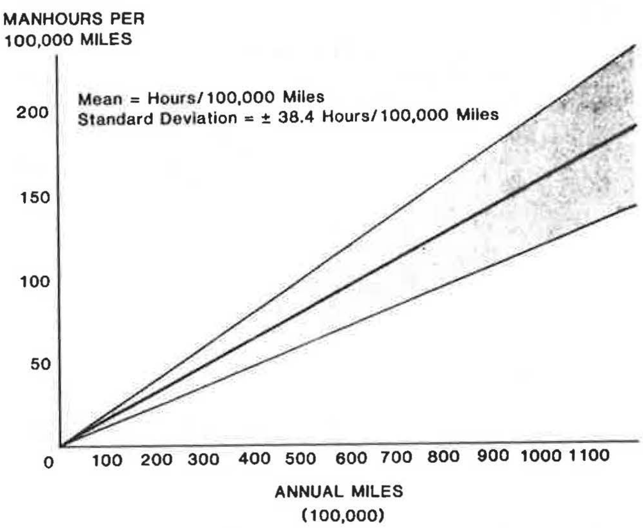

FIGURE 7 Engine and fuel man hours

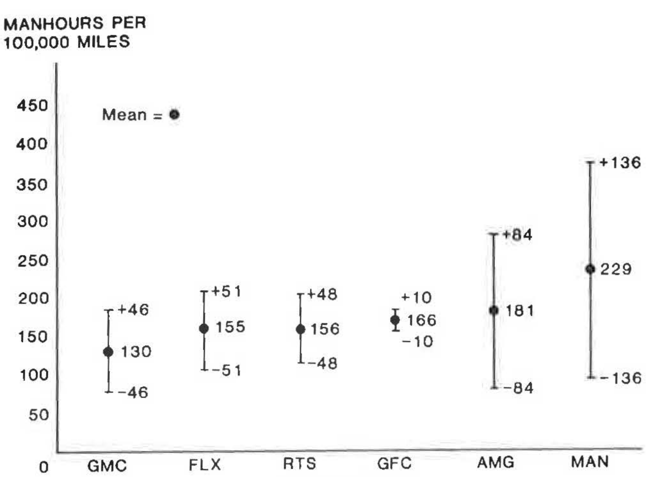

FIGURE 8 Engine and fuel man hours by vehicle type.

Some caution must be exercised in reviewing subfleet labor requirements. These numbers are based on the experience of 15 transit agencies as reported to the research team. Figure 8 shows that differences exist but not why. Subfleet line speed, mechanic training, vehicle age, facilities, and equipment may all affect man-hour requirements. For example, the M.A.N. articulated vehicle exhibited both the highest mean time for maintenance and the largest standard deviation. Further investigation revealed that two agencies with high mean times were using the vehicles in very low-speed service and one was repairing the vehicles in facilities designed for 40-ft buses. Conversely, the two agencies with lower values were using the vehicles exclusively in high-speed service. Because line-speed data were not collected by subfleet, the research team was unable to develop a mathematical relationship between man-hour requirements by subfleet and speed.

Braking

The braking subsystem is made up of running repair and reline work applied to the parking brake and the front, drive, and third axles (when applicable) of revenue buses. On the average, braking man hours accounted for 7 percent of total maintenance labor hours. Actual braking hours ranged from a low of 1,700 to a high of 132,000 man-hr per year in the survey group. The primary factors driving the difference are miles of operation, line speed, and vehicle type.

The coefficient of correlation between braking hours and vehicle miles was 75 percent, leaving 25 percent of the deviation not accounted for by vehicle miles. When supplemented with average systemwide speed, the correlation rose another 3 percent to 78 percent. Because of the relatively low correlation, systemwide speed was disregarded. When analyzed by subfleet (i.e., vehicle manufacturer), the correlation of vehicle miles and subfleet to man hours rose to 88 percent. The remaining standard error of 12 percent is probably attributable to terrain, average speed by subfleet, training, and facilities. The research team did not obtain numerical values for these items, so evaluating mathematical relationships between these variables was not possible.

On the average, transit agencies required 123.5 man-hr per 100,000 vehicle miles to make brake repairs, as shown in Figure 9. The standard deviation was ±31.0 hr per 100,000 miles. The majority of this deviation in the study group can be accounted for by the differences in vehicle type (i.e., manufacturer). The range reported by fleet manufacturer, shown in Figure 10, ranges from a low of 102 man-hr per 100,000 miles for Flxible to a high of 158 man-hr per 100,000 miles for GFC. The standard deviation by subfleet averages 44 percent, with RTS (advanced design of GMC) at the low end (23 percent standard error) and M.A.N. at the high end (69 percent standard error). Again, this measure only shows what occurred and not why vehicles accounted for different man-hour amounts.

Although numerical values were not available for terrain, agencies with hilly or mountainous terrain had values on the high side of the mean for each vehicle type. Correspondingly, agencies with flat terrain generally had values on the low side of the mean. Speed is believed to have a significant impact on braking repair as well, although speed by subfleet was not available in this study. However, the four agencies with M.A.N. articulated vehicles did identify relative speeds for these vehicles. Two operators used M.A.N. vehicles almost exclusively in low-speed service, and both appeared well above the

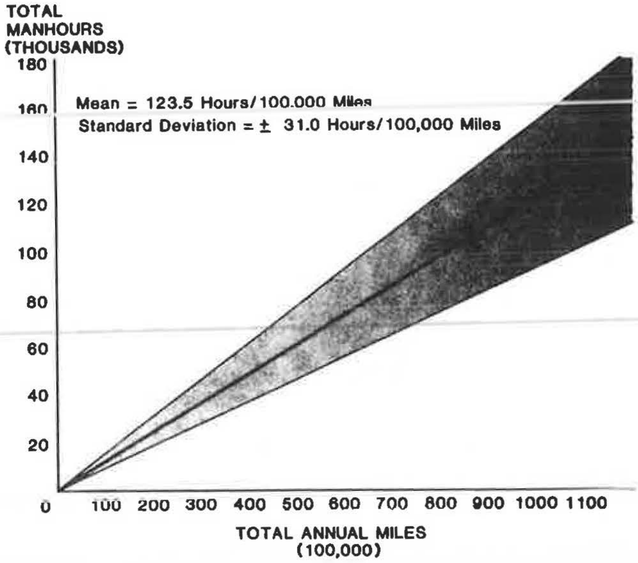

FIGURE 9 Braking man hours.

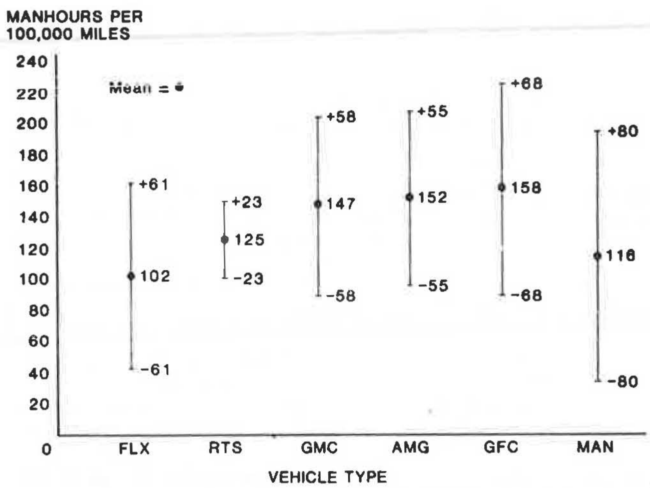

FIGURE 10 Braking man hours by vehicle type.

mean-hour requirement. The other two operators used these vehicles primarily in high-speed service, and both ended up well below the mean time for repair.

Other variables may contribute to vehicle type times as well, including mechanic skill and training levels and facility and support equipment availability.

Electrical Subsystem

The electrical subsystem is made up of running repair, removal and replacement, and rebuild activities for starters, alternators and generators, batteries, and miscellaneous electrical components. Overall, electrical work accounts for 6 percent of total maintenance manpower. Annual work hours range from 1,400 to 151,000 for this subsystem. The difference is primarily attributable to vehicle miles and subfleet type, although climate may have a minor impact.

The coefficient of correlation between electrical man hours and vehicle miles is 75 percent, leaving 25 percent of the variation not accounted for by miles. When the secondary variable of vehicle type is also evaluated, correlation rises to 94.5 percent, leaving a standard error of only 5.5 percent. Both climate and speed were evaluated as potentia independent variables, but no significant correla tion was found.

On the average, the survey agencies required 9 man-hr per 100,000 miles for electrical repair, a shown in Figure 11. The standard deviation was ±24. hr. Most of this deviation is explained by vehicl mix, as shown in Figure 12. Electrical man-hou requirements ranged from an average of 92 man-hr pe 100,000 miles for RTS vehicles to an average of 14 hr per 100,000 miles for GFC vehicles. Each vehicle type had a relatively high standard deviation, ranging from 29 percent to 85 percent of their respective means. Again, it is believed that subfleet speed, mechanic training, and climate affect subfleet repair times. However, numerical data are not available to support or refute the premise.

Air, Steering, and Suspension

At the onset of the research program, air, steering, and suspension were all evaluated as separate subsystems. The survey agencies, however, combined and separated the components of these systems in dif-

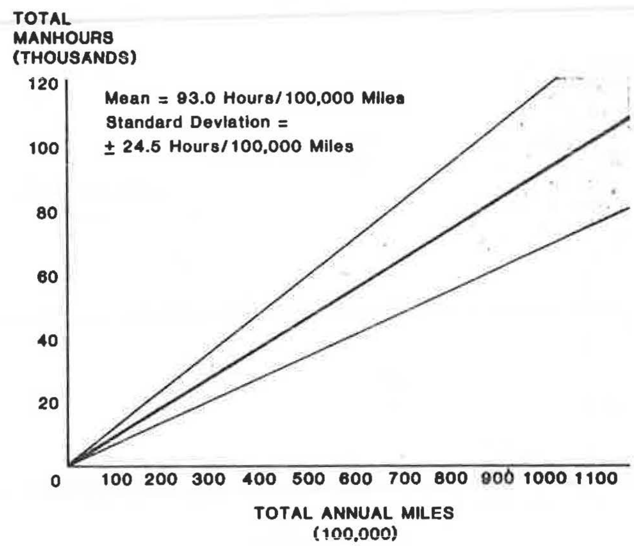

FIGURE 11 Electrical subsystem man hours.

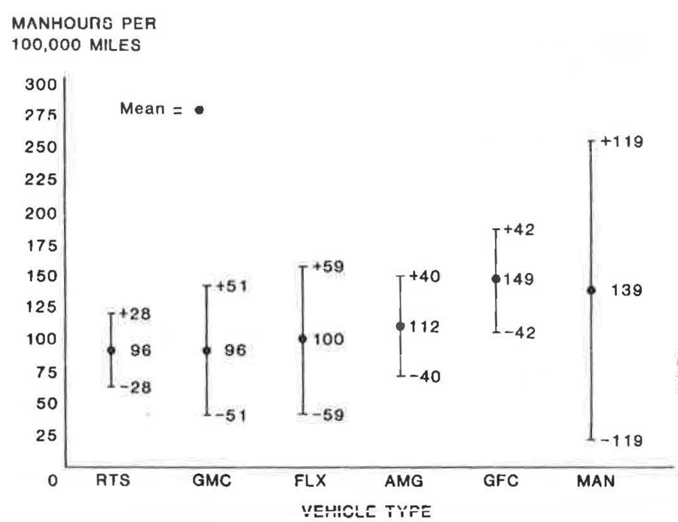

FIGURE 12 Electrical subsystem man hours by vehicle type.

'erent forms. When analyzed independently, the re-sults were misleading because data were not con-sistent. The problem of comparability was overcome by combining the three related subsystems into one. The air, steering, and suspension subsystem is made up of running repair, removal and replacement, and rebuild activities for all primary components of these systems.

Overall, this subsystem accounts for 5 percent of maintenance man hours, ranging from 3,200 to 90,000 man-hr per year in the survey group. The primary independent variable driving the difference is vehicle miles of operation.

The coefficient of correlation between air, steering, and suspension man hours and vehicle miles was 66 percent, with 34 percent of the variation not accounted for by miles of operation. Correlation analysis was also conducted by using average speed and climate as independent variables, but no significant relationship was found. Steering and suspension repair hours are probably related to road conditions (e.g., potholes), although no numerical data were available to evaluate this factor.

On the average, the survey agencies required 76.5 man-hr per 100,000 miles to maintain air, steering, and suspension systems, as shown in Figure 13. The standard deviation was ±26.0 hr per 100,000 miles. It is difficult to account for the remaining difference, because road condition data were not collected in this research effort.

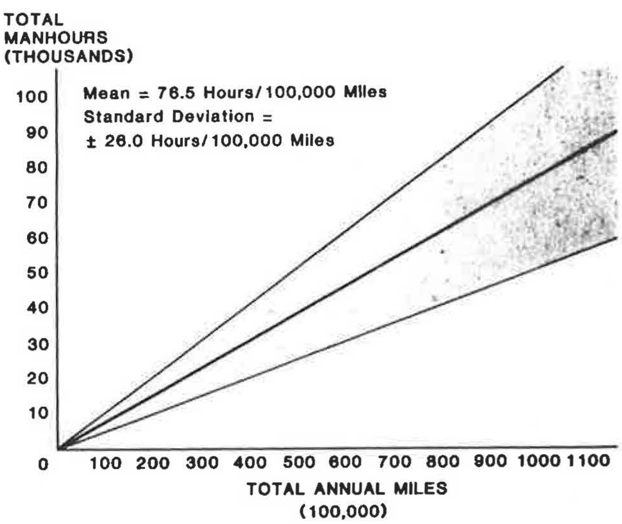

FIGURE 13 Air, steering, and suspension man hours.

Air Conditioning, Heating, and Ventilation

Air conditioning, heating, and ventilation were initially analyzed as separate subsystems. However, the two are quite interrelated and in the final evaluation the analysis worked best when the areas were combined. The air conditioning, heating, and ventilation subsystem is made up of running repair, removal and replacement, and rebuild work on all applicable components.

Overall, this subsystem accounted for 5 percent of total maintenance man hours, ranging from a low of 1,500 to a high of 69,000 man-hr for the survey agencies. The two major factors causing the difference are vehicle miles and climate.

The coefficient of correlation between vehicle miles and climate (independent variables) and air conditioning, heating, and ventilation hours (dependent variables) is about 87 percent. Average speed was also analyzed but only exhibited a minute relationship with man hours. Much of the remaining deviation can be attributed to policy. Some agencies have policy mandates to keep all air conditioners functioning, whereas others will accept some failures.

The mean and standard deviation for hot and humid summers is 168.5 and 52.0 man-hr per 100,000 miles, respectively (Figure 14). Hot and dry climates reported a mean of 83.5 hr per 100,000 miles. Agencies with a cool and mild summer (i.e., those that generally operate without air conditioning) reported a mean of 27.0 hr per 100,000 miles and a standard deviation of 17.0 hr. The remaining deviation here is chiefly attributable to the winter climate, which ranges from mild in the northwestern United States to severe in the Rocky Mountains.

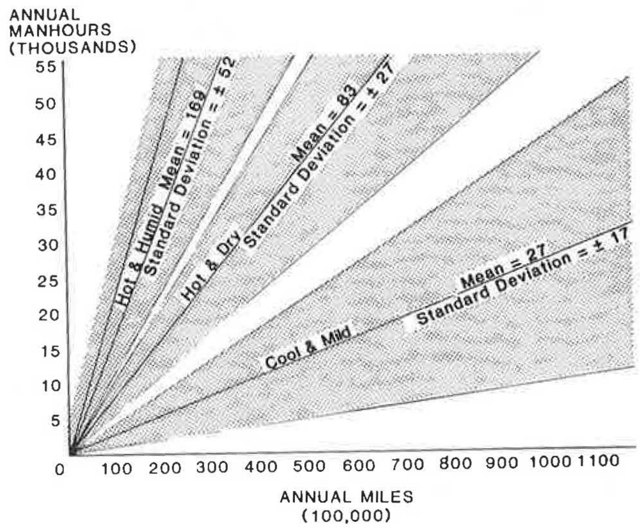

FIGURE 14 Air conditioning, heating, and ventilation man hours.

Drivetrain

The drivetrain subsystem is made up of running repair, removal and replacement, and rebuild work on the transmission and differential. Tearing down, cleaning, and rebuilding of small accessories are also included here. Overall, the drivetrain subsystem accounts for 5 percent of total maintenance man hours and ranges from 1,100 to 88,600 man-hr per year in the survey agencies. The difference is a function of vehicle miles, transmission type, and vehicle speed.

The coefficient of correlation between drivetrain man hours and miles of operation is 77 percent. An additional 14 percent is added by examining transmission type, bringing the total correlation up to 91 percent. Average speed on the systemwide level added 6 percent but was not available on the subfleet level and therefore was omitted.

On the average, the survey agencies reported 73 man-hr per 100,000 miles for drivetrain maintenance, as shown in Figure 15. The standard deviation was ±17 hr, mostly a function of the type of transmission accumulating miles. As shown in Figure 16, mean drivetrain labor-hour requirements ranged from an average of 58 man-hr per 100,000 miles for the V730 to an average of 139 man-hr per 100,000 miles for the Renk Dormat 874A. The VH and VS transmissions were grouped together in the manpower reporting, and the mean repair time for these transmissions was reported as 135 man-hr per 100,000 miles.

The deviation of man hours by transmission type

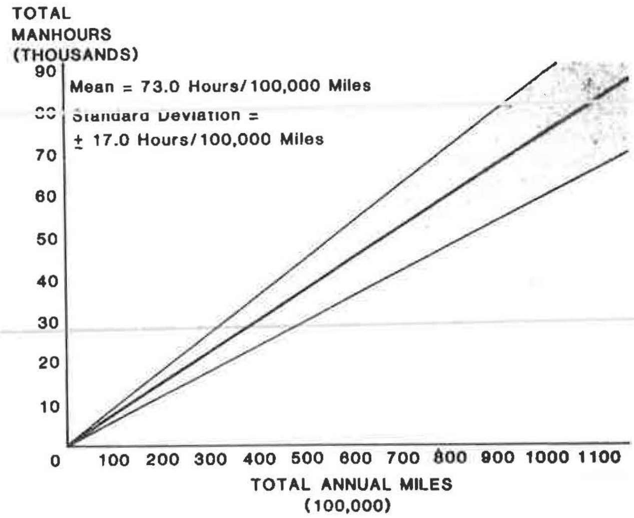

FIGURE 15 Drivetrain man hours.

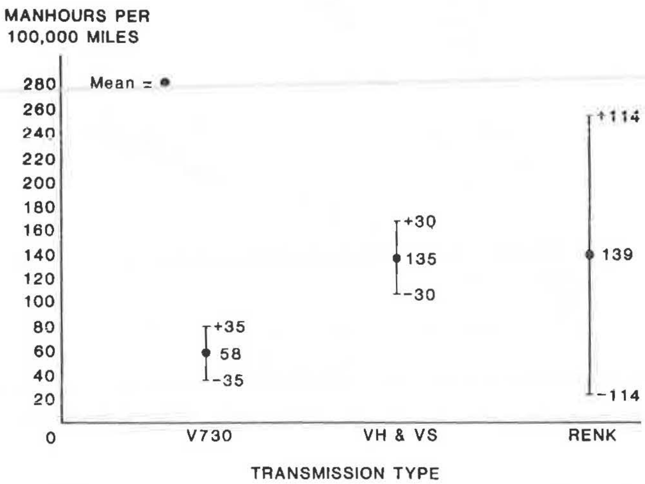

FIGURE 16 Drivetrain man hours by transmission type.

is believed to be a function of line speed. Although speed numbers were not available by subfleet, there was a correlation at the systemwide level. In addition, two operators using the Renk drivetrain almost exclusively in slow-speed service were at the upper end of manpower requirements. Conversely, the two operators using Renks primarily in high-speed service were on the lowest end of the man-hour requirements.

Accessories

The accessories subsystem is composed of farebox, destination sign, and wheelchair lift. Each of these components was analyzed separately, because agencies varied substantially with regard to contracting policies and components used. Overall accessories accounted for 5 percent of total maintenance man hours. The primary factor determining man-hour requirements is the number of active vehicles equipped with the particular component.

The coefficient of correlation between total accessory repair hours and active vehicles is 62 percent. The standard error of 38 percent results because different agencies have different accessories and policies regarding acceptable failure levels.

Mechanical fareboxes required a mean of 11. man-hr per active vehicle, with a standard deviatio of ±7.2 hr for repair, as shown in Figure 17. Onl two agencies operated electronic fareboxes; the were excluded for lack of data. Two types of destination signs were used--curtain and electrical (do matrix). The curtain signs averaged 7.3 man-hr pe vehicle and electrical signs averaged 6.0 man-hr Wheelchair lift repair exhibited the greatest deviation, with a mean of 14.7 hr and standard deviatio of ±19.3 hr. Several agencies had lifts on every bus and were required to keep them functional at all times. Other agencies found some failure rate acceptable, and this required fewer maintenance hours.

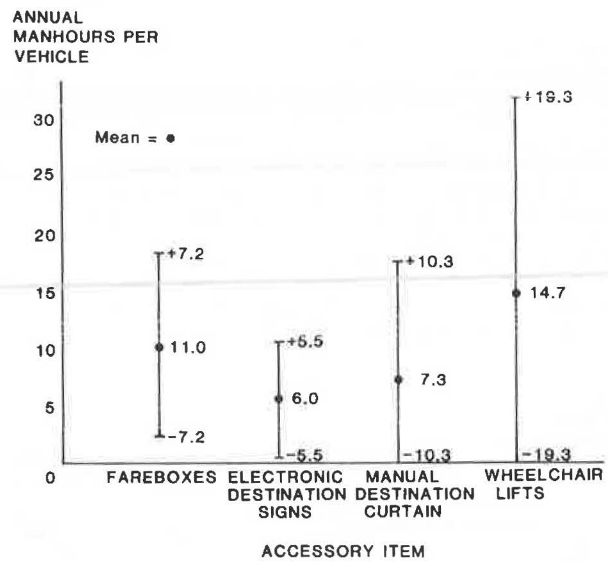

FIGURE 17 Accessory man hours.

Cooling

The cooling function is made up of all maintenance activities on the vehicle's engine cooling subsystem. Overall, the cooling subsystem accounts for 3 percent of total manpower and ranges from 300 to 45,900 man-hr per year in the survey agencies. The primary cause of the deviation is miles of operation; summer climate also has a significant impact.

The coefficient of correlation between the independent variables of vehicle miles and climate to cooling man hours is about 75 percent. For the purposes of this analysis, agencies were divided into two groups--those with hot summers and those with relatively mild summers.

The mean cooling maintenance hours per 100,000 miles for hot summers was 65, as shown in Figure 18. The standard deviation was ±16 hr per 100,000 miles. The agencies with moderate summer temperatures reported substantially lower man-hour needs with a mean of 37 hr per 100,000 miles and a standard deviation of ±12 hr.

Wheels and Tires

It is important to note that many agencies contract for tire work, and little or none is done in house. Of the 15 agencies in the sample size, 7 do not work on tires in house and the remaining 8 vary. Some only remove and replace tires, whereas others repair all failures occurring in the swing and night shifts and have the contractor repair those that can wait until the day shift. Overall, wheels and tires ac-

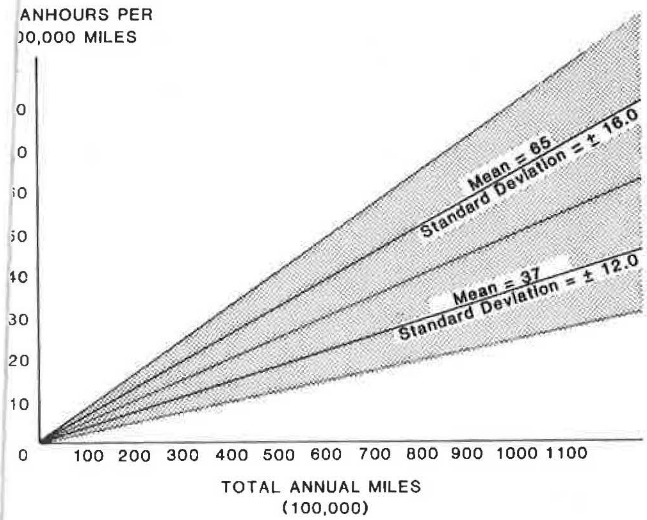

FIGURE 18 Cooling man hours by climate.

counted for only 1 percent of total maintenance man hours.

The coefficient of correlation between wheel-and-tire man hours and vehicle miles is only 57 percent. Although the error is substantial, it is primarily a function of different contracting arrangements and is not easily quantified. On the average, agencies that engaged in some wheel-and-tire repair reported 48.6 man-hr per 100,000 miles. The standard deviation was ±21.0 hr.

Unavailable Time at Work

In addition to work hours, all transit agencies pay labor for some amount of time not spent maintaining vehicles. Paid coffee breaks, clean-up time, and paid lunch breaks are the most common forms of unproductive time at work. The existence of these contractual arrangements expands the need for manpower to conduct the productive work identified in previous sections.

The expansion factor can be estimated by multiplying the number of minutes that maintenance staff is unavailable for work per day by 0.0025 and adding 1. In the survey group, agencies reported an average of 45 min per day in unavailable time. This translates to an expansion factor of 1.103. The highest unavailable time was 90 min per day, which requires an expansion factor of 1.231. The lowest unavailable time was 30 min, or an expansion factor of 1.067.

Time Not at Work

In addition to unavailable time on the job, staff members are unavailable for some period because they are not at work. Days not at work include holidays, vacation, sick leave, worker's compensation, time off, jury duty, and a host of other unavailable days. The workday hours calculated in the previous step must be further expanded to reflect employee days not at work.

The expansion factor can be estimated by multiplying unavailable days by 0.0052 and adding 1. On the average, agencies reported 37 unavailable days per person per year. This translates to an expansion factor of 1.166. The highest unavailable days reported was 44.1 days per person per year, or an expansion factor of 1.204. The lowest unavailable days per employee was 29.1, or an expansion factor of 1.126.

Overtime

Unlike unavailable time, overtime reduces the manpower requirement in terms of bodies, because each person works more than one full man year. Therefore, the expanded man-hour figure must be compressed by the amount of overtime used before hours are translated into staffing levels.

The overtime compression factor can be estimated by subtracting the proportion of total work hours conducted at overtime from 1. The compression factor is then multiplied by expanded hours to produce staff hours. On the average, survey agencies reported that 5.8 percent of hours were worked overtime. The range of overtime was large, from 0.2 percent to 19.2 percent of total work hours.

SUMMARY

Maintenance manpower requirements vary substantially among transit agencies; local operating characteristics account for much of the difference. The work summarized in this paper represents a first step toward understanding the causal factors driving maintenance manpower requirements for transit diesel buses. The study culminated in the development of an uncomplicated maintenance manpower planning technique in both numeric and graphic (i.e., nomograph) forms. The entire study is documented in an NCTRP publication (1).

ACKNOWLEDGMENTS

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Without the cooperation of many transit agencies, the project would not have been possible. Staff members from these agencies willingly took time from their busy work schedules to assist in the project. They are too numerous to name individually, but each agency that participated throughout the study is acknowledged: Albuquerque Transit System; Ann Arbor Transit System; Austin Transit System; Chicago Tran-

sit Authority; Des Moines Metropolitan Transit Authority; Orange County Transit District; Regional Transportation District, Denver; Regional Transit Authority, New Orleans; Salem Area Mass Transit District; Seattle Metro; Southeastern Pennsylvania Transit Authority; Southern California Rapid Transit District; Tri-County Metropolitan Transportation District, Oregon; Utah Transit Authority; and Washington Metropolitan Area Transit Authority.

REFERENCE

1. Public Transit Bus Maintenance Manpower Planning. NCTRP Report 10. TRB, National Researc Council, Washington, D.C., Oct. 1984.

Publication of this paper sponsored by Committee o Transit Bus Maintenance.

Space Allocation in Bus Maintenance Facilities

STEPHEN J. ANDRLE and BRIAN McCOLLOM

ABSTRACT

A summary is given of the findings of a research effort sponsored by UMTA to identify the space guidelines used in the transit industry to plan bus maintenance facilities. Data from 30 maintenance facilities built within the last 15 years were analyzed by examining the statistical relationships between the space allocations within the facilities and variables such as annual vehicle miles operated, fleet size, and employees on site. Although the relationships derived from this research reflect as-built and not necessarily desired conditions, they can be used as guidelines for the initial feasibility phases of facility planning.

UMTA initiated a project in 1982 to develop a handbook on the planning of bus maintenance facilities. Although close to 100 new bus maintenance facilities have been constructed in the United States in the last 15 years, most with financial assistance from UMTA, only limited information is available on the major parameters and guidelines that should be used in the planning of such facilities. The last major work in this area was a 1975 report prepared for UMTA by the Mitre Corporation (1). The guidelines in that report were developed from a survey of existing maintenance facilities, a number of which were designed for streetcar, not bus, use. The purpose of the current UMTA study is to update this report and develop guidelines based on current practice in bus facility planning.

This paper is a summary of the first phase of the UMTA study--the inventory of space guidelines being used to size bus maintenance facilities. An unsuccessful attempt was made to contact transit systems where facilities had been recently constructed. Unfortunately, most of the systems had not documented the guidelines that were used in their facility planning. Therefore, an alternative approach was used in which the guidelines were derived from data on recently constructed facilities.

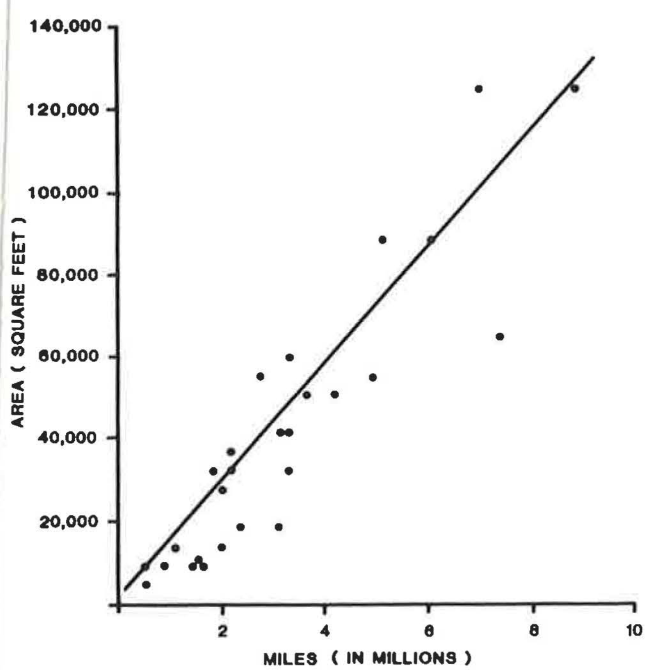
The data were assembled for more than 30 facilities built within the last 15 years. Planning and design documents were requested for each facility; however, in most cases, the amount of space that was provided for the various maintenance functions was obtained by scaling drawings of as-built facilities. These data were analyzed by examining the statistical relationships between the provided space and the operating characteristics of each facility such as annual vehicle miles operated, fleet size, and employees on site. The analyses were controlled for system type (i.e., single or multiple maintenance facility system) because of the different kinds of facilities that are built in these systems.

The functional areas of a maintenance facility were grouped into four categories: maintenance, bus servicing, transportation (e.g., drivers' dayroom, dispatching), and office space. Regression analysis was used to examine the amount of space provided both for each category and for each function within the category. For example, relationships were tested for the amounts of space provided for the total maintenance category and the subareas within the maintenance category such as maintenance bays, parts and storage areas, and the tire shop. The results of these tests are presented in the following sections.

MAINTENANCE

Maintenance services include all maintenance bay areas and shops but exclude service lanes and vehicle storage. The amount of maintenance space required to properly service a fleet is dependent primarily on the amount of revenue service operated from the facility and secondarily on the number of ehicles in the fleet. Because vehicles in most ystems cannot be operated more than 12 to 16 hr per lay, annual vehicle miles tends to reflect both the size and utilization of the fleet. Accordingly, annual vehicle miles should be a better indicator than fleet size of maintenance space needs.

This expectation was confirmed in the analysis. The best statistical relationship was 1,400 ft^2 of maintenance service area per 100,000 annual vehicle miles plus 564 ft^2 (Figure 1). This includes all maintenance bay areas, shops, and service lanes but excludes vehicle storage.



TOTAL MAINTENANCE AREA REGRESSION EQUATION

```
y = 1389x +  564
    (129)    (4763)   STANDARD ERROR OF
                      REGRESSION COEFFICIENT
    (10.81) (0.12)    T-VALUE
    (0.00)  (0.45)    SIGNIFICANCE OF T-VALUE
r2 = 0.82             NUMBER OF CASES = 27
x = ANNUAL VEHICLE MILES IN 100,000'S
y = TOTAL MAINTENANCE AREA IN SQUARE FEET
```

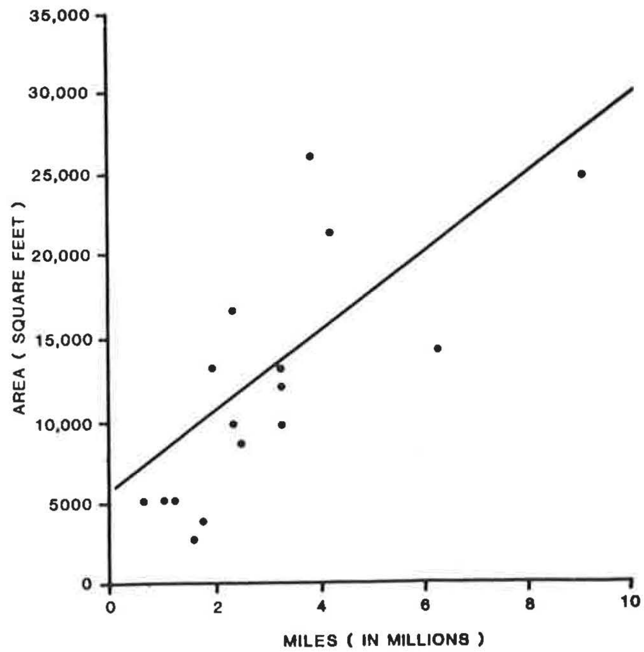
FIGURE 1 Total maintenance area analysis.

Maintenance Bays

The maintenance bay is the area that is provided to work directly on the bus. It includes space for all maintenance functions with the exception of servicing and work conducted in shops.

A statistical relationship for the maintenance bay area was only found for single-facility systems. The best relationship for single-facility systems was 5,600 ft^2 plus 250 ft^2 per 100,000 annual vehicle miles (Figure 2). A similar relationship was observed for multiple-facility systems; however, its coefficient of determination was poor (R^2 = 28).

The poor relationship for multiple-facility systems may be attributed to the small number of cases in which data were available and to differences in the maintenance programs among the systems. Data were only available on eight multiple systems. Strong relationships are often difficult to identify with such a small number of observations. The maintenance programs also tended to vary more among multiple-facility systems. Unlike single-facility



MAINTENANCE BAY AREA REGRESSION EQUATION: SINGLE FACILITY SYSTEMS

```
y = 246x  +  5628
    (62)     (2137)   STANDARD ERROR OF
                      REGRESSION COEFFICIENT
    (3.95)  (2.64)    T-VALUE
    (0.00)  (0.01)    SIGNIFICANCE OF T-VALUE
r2 = 0.53             NUMBER OF CASES = 16
x = ANNUAL VEHICLE MILES IN 100,000'S
y = TOTAL MAINTENANCE BAY AREA IN
    SQUARE FEET
```

FIGURE 2 Maintenance bay area analysis: single-facility systems.

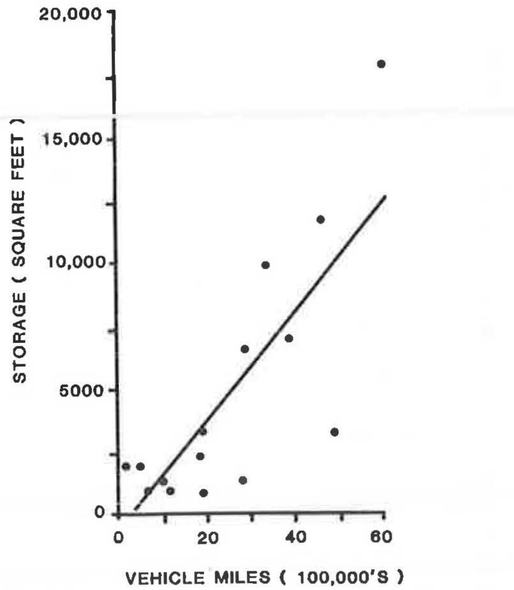
systems, space is not provided for all maintenance functions in multiple-facility garages; painting, body work, and overhaul work are often concentrated in a heavy-maintenance garage. However, the degree to which these maintenance functions are centralized varies among systems and thus produces less stable space relationships.

Parts and Other Storage

Lack of parts storage is a problem in some older facilities. Many transit systems are operating a greater variety of vehicles than in the past--smaller buses, standard buses, and articulated buses. A larger parts inventory must be maintained to accommodate this variety.

Different parts storage relationships were found for single- and multiple-facility systems. Over 230 ft^2 per 100,000 annual vehicle miles is provided in single-facility systems (Figure 3), whereas a little more than half of that amount (126 ft^2) is provided in multiple-facility systems (Figure 4). Again this difference may be attributed to the more limited maintenance activities that are typically conducted at operating garages in multiple-facility systems.

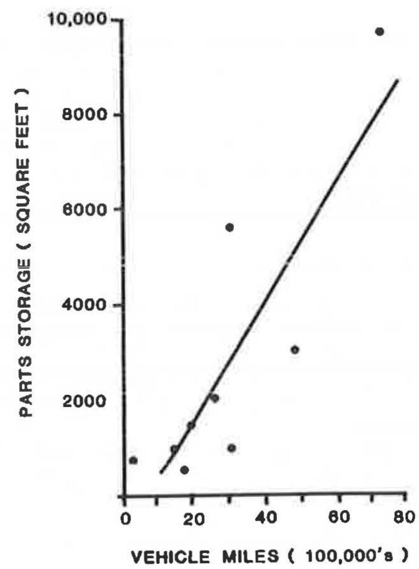
In addition to the parts room, space must be allocated for other storage--grease, fluids, detergent, body parts, and spare engine and transmission units. A relationship of approximately 50 ft^2 per 100,000 annual vehicle miles was found for single-facility systems (Figure 5). No significant relationship was identified for multiple-facility systems; the variability among these systems in the maintenance activities conducted may be an explanation.



PARTS STORAGE REGRESSION EQUATION:
SINGLE FACILITY SYSTEMS

y = 233x - 1923
(56) (1668) STANDARD ERROR OF REGRESSION COEFFICIENT
(4.18) (1.15) T-VALUE
(0.00) (0.14) SIGNIFICANCE OF T-VALUE
r^2 = 0.59 NUMBER OF CASES = 14
x = ANNUAL VEHICLE MILES IN 100,000'S
y = PARTS STORAGE AREA IN SQUARE FEET

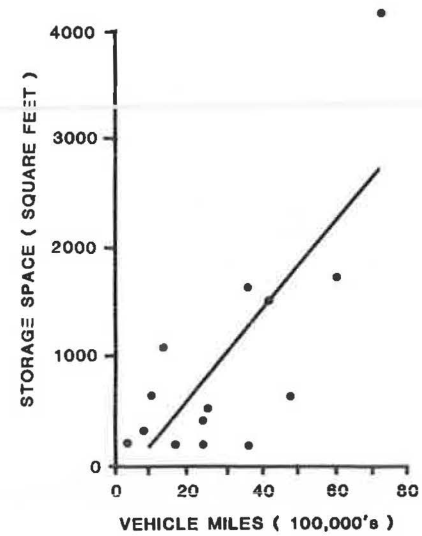
FIGURE 3 Parts storage area analysis: single-facility systems.



PARTS STORAGE REGRESSION EQUATION:
MULTIPLE FACILITY SYSTEMS

y = 126x - 821
(29) (1010) STANDARD ERROR OF REGRESSION COEFFICIENT
(4.41) (0.81) T-VALUE
(0.00) (0.22) SIGNIFICANCE OF T-VALUE
r^2 = 0.74 NUMBER OF CASES = 9
x = ANNUAL VEHICLE MILES IN 100,000'S
y = PARTS STORAGE AREA IN SQUARE FEET

FIGURE 4 Parts storage area analysis: multiple-facility systems.



MAINTENANCE STORAGE SPACE REGRESSION
EQUATION: SINGLE FACILITY SYSTEMS

y = 52x - 402
(12) (451) STANDARD ERROR OF REGRESSION COEFFICIENT
(4.10) (0.90) T-VALUE
(0.00) (0.20) SIGNIFICANCE OF T-VALUE
r^2 = 0.58 NUMBER OF CASES = 14
x = ANNUAL VEHICLE MILES IN 100,000'S
y = MAINTENANCE STORAGE SPACE IN SQUARE FEET

FIGURE 5 Maintenance storage space analysis: single-facility systems.

Tire Shop

Two types of tire shop arrangements are found. In one case a work bay is dedicated to tire work and storage is included in the bay area. This bay is often walled off from the rest of the facility. The other common arrangement is a dedicated room that does not include a work bay.

The size of the tire shop was relatively uniform and did not appear to be related to any measure of system size or use. The average size of a tire shop without a dedicated work bay was 517 ft^2, whereas the average size of a tire shop with a dedicated work bay was 2,141 ft^2. There was greater variation in size among tire shops with a dedicated work bay (standard deviation = 1,021 ft^2) than among those without a dedicated work bay (standard deviation = 135 ft^2). This may be attributable to the dedication of more than one work bay in some tire shops.

Brake Shop

Only 20 percent of the facilities examined had separate areas dedicated to brake repair. Like tire shops, a dedicated room and a dedicated work bay are the two types of brake shops that were found. In facilities without brake shops one or more bays are used for brake work but are not exclusively assigned to brakes. Brake lathes are placed reasonably close to the bays in these cases and the brake drums are wheeled to the lathes on dollies.

The limited number of facilities with dedicated brake shops made it impossible to examine any statistical relationships. The size of the brake shops without dedicated bays ranged in size from 140 to 608 ft^2, whereas the brake shops with dedicated bays ranged in size from 1,250 to 2,300 ft^2.

TABLE 1 Other Maintenance Support Areas

	Space (ft^2)				
Functional Area	No. of Cases	Mean Value	Low Value	High Value	Standard Deviation
Battery room	21	235	80	720	150
Body shop	16	2,835	264	9,550	2,452
Dynamometer bay	4	1,719	1,229	2,200	
Electrical shop	4	291	140	510	
Injection repair shop	5	187	104	423	
Overhaul shop	12	2,324	163	7,100	1,780
Paint shop	12	2,037	810	5,575	1,365
Parts cleaning area	6	500	169	825	
Steam cleaning area	18	1,148	220	1,950	411

Other Support Areas

There were a number of maintenance support areas for which no relationships were found. No systematic relationships to annual vehicle miles, fleet size, or any other measures of system operations were identified. Likewise, as shown in Table 1, the size of these areas was not uniform and appeared to vary almost randomly.

There are a number of reasons that may partly explain the apparent absence of statistical relationships. One is the way in which these areas are considered in the design process. Interviews with a number of systems suggested that the initial space may be allocated for the entire support area and not for individual activities. The breaking up of this space for individual activities is influenced not only by the nature of the activity but also by location of load-supporting walls, column placements, and the physical shape of the facility.

Another reason is the small number of facilities in the sample that contained some of these other support areas. As shown in Table 1, four of the nine functional areas had less than seven cases. Even when there is an underlying relationship, it is difficult to identify it statistically when the number of cases is this small.

A final reason may be that the space required for a number of the areas is small and can be significantly changed by the addition of a few feet in a dimension. For example, the size of a 20 x 25-ft battery room can be increased 25 percent from 550 to 625 ft^2 by simplying increasing the first dimension by 5 ft. When the dimensions are small, small absolute changes in dimensions can produce large percentage changes in area.

BUS SERVICING

This category consists of three bus activities that are performed on a routine basis: daily servicing, vehicle inspection, and parking. These activities are usually performed by employees from the maintenance department, although in some instances transportation department employees are involved. The number of buses in the fleet was found in the analysis to provide the best statistical relationship for daily servicing and parking areas, whereas annual vehicle miles provided the best relationship for inspection area. No statistical analysis was performed for the category as a whole because of the disparate nature of the activities within the category.

Daily Servicing

Bus servicing is a daily function for most of the active fleet. Farebox vault pulling, refueling, fluid checking, and interior and exterior cleaning are activities that are often done as part of daily servicing.

The most common servicing arrangement is an in-line pattern. At the first station, vault pulling is performed; at the second, combined refueling, fluid checking, and interior cleaning; and at the third, drive-through exterior washing. Typically, one or two service lanes are provided that bypass the exterior wash station to accommodate servicing when washing is unnecessary.

There are variations on this basic arrangement. One variation that is popular for reasons of security is to pull the farebox vaults at the front gate so no buses on the property have cash aboard. Some systems believe that this is very important and others find it sufficient to pull farebox vaults in the service lanes. If farebox vaults are pulled at the front gate, a driveway long enough to prevent bus queuing on the street is provided.

Another variation is to segregate washing entirely from other servicing activities. The long service lanes act as a wind tunnel. The spray from the exterior washers blows back through the servicing area making an unpleasant working environment, especially in the winter. One facility that has adopted this strategy designed a free-standing building for servicing and interior cleaning and constructed two wash bays at the end of the main building. The site circulation plan featured counterclockwise movement from the vaulting station at the front gate to the service building to the washer. Because the washer is at the end of the building, the washer bypass route is simply around the end. This facility is in the South, so the exterior circulation is not a problem.

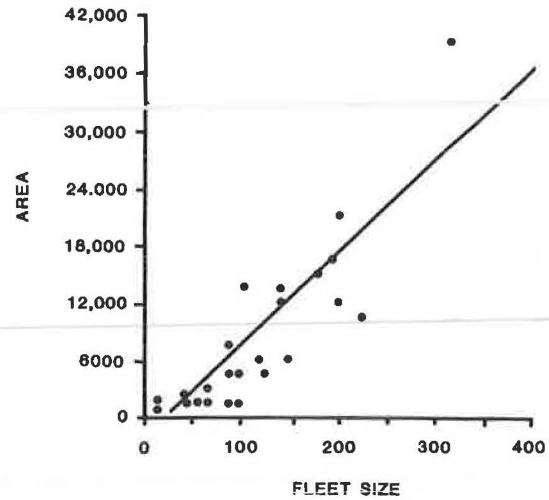
The best statistical relationship for service area was approximately 100 ft^2 per bus in the active fleet (Figure 6). This relationship appears reasonable because every bus that operates during the day is generally serviced regardless of the miles that it travels.

Vehicle Inspection

Like daily servicing, vehicle inspection is a frequent activity. Almost all transit systems perform thorough inspections at fixed mileage intervals that range from 3,000 to 6,000 miles. In addition, daily safety inspections or brake adjustments or both are performed in the inspection area at some transit systems.

Most transit systems prefer pits for inspection because a bus can be moved over a pit more quickly than it can be raised on a hoist. Whether pits or hoists are used, inspection areas are generally designed as drive-through lanes to minimize the time that is required to maneuver the vehicles.

The best statistical relationship was 0.045 lane



SERVICE AREA SPACE REGRESSION EQUATION

y = 99x −	2771	
(12)	(1727)	STANDARD ERROR OF REGRESSION COEFFICIENT
(8.21)	(1.60)	T-VALUE
(0.00)	(0.06)	SIGNIFICANCE OF T-VALUE
r^2 = 0.75		NUMBER OF CASES = 25

x = ANNUAL VEHICLE MILES IN 100,000'S
y = SERVICE AREA IN SQUARE FEET

FIGURE 6 Service lane area analysis.

per 100,000 annual vehicle miles plus 0.667 lane (Figure 7). The use of service area as a dependent variable did not produce a significant relationship, probably because most of the facilities used the drive-through design. When this design is used, the placement of exterior doors and internal circulation lanes can greatly influence the size of the inspection area.

As shown in Figure 7, the relationship between the number of inspection lanes and annual vehicle miles has a relatively low coefficient of determination (R^2 = 0.51). This occurs in part because the number of inspection lanes is a discontinuous variable. The plot in Figure 7 suggests that a step function may exist where an additional inspection lane is added every 1.5 million to 2.0 million annual vehicle miles.

Parking

The most significant new development in bus parking is the provision of indoor parking in areas with inclement weather. The pattern in the sample transit systems was to provide indoor parking where the temperature drops below 32° F more than 100 nights per year.

Where indoor parking is provided, it is usually in-line parking. This is the most space-efficient parking pattern. Where outdoor parking is provided, in-line stacking is used only in the most restrictive cases, because buses are not easily accessible. Angle parking or double-angle parking is preferred because each individual bus is always accessible. These patterns require more space than in-line parking, but they are preferred when the acreage is available. Double-angled parking requires almost twice as much space per bus as conventional in-line stacking because of the additional circulation lanes. Single-angled parking requires almost three times the space of in-line stacking (2):

Parking Type	Required Space per Bus (ft^2)
In-line	504
Double, 30-degree angle	920
Single, 30-degree angle	1,450
Single, 60-degree angle	1,325
Single, 45-degree angle	1,465

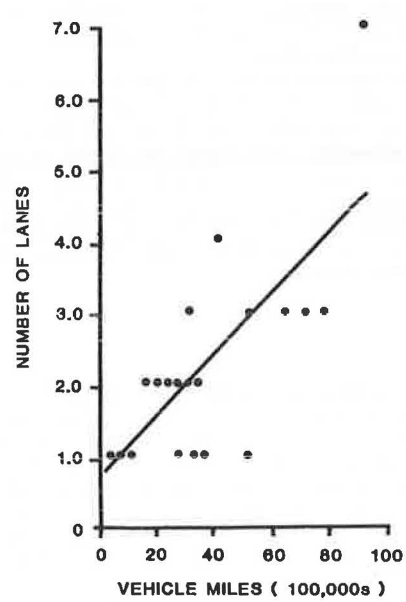
In some climates transit agencies have opted for total internal circulation and storage. Where winters are severe, internal circulation insulates the maintenance operation from the effects of weather. Buses do not have to "drip dry" before maintenance work is conducted, and shuttling buses to the shop from the parking area is never impaired by snow on the lot. Systems that have internal storage and circulation claim that the quality of maintenance improves.

The cost trade-offs for the benefit of improved maintenance are a larger building and a more elaborate ventilating system. It is necessary to have heat exchangers and a high rate of air turnover in the parking area when internal circulation is used. Because there are fewer doors, the old system of opening the storage garage doors for ventilation during pull-outs and pull-ins cannot be used.

The best statistical relationship for indoor parking was approximately 500 ft^2 per bus in the active fleet plus 2,665 ft^2 (Figure 8). This finding is consistent with the space recommendations that were cited for in-line parking earlier in this section. No data were available to analyze the provision of external parking space.

TRANSPORTATION

Transportation space includes the drivers' dayroom and locker room and dispatching offices. Fleet size

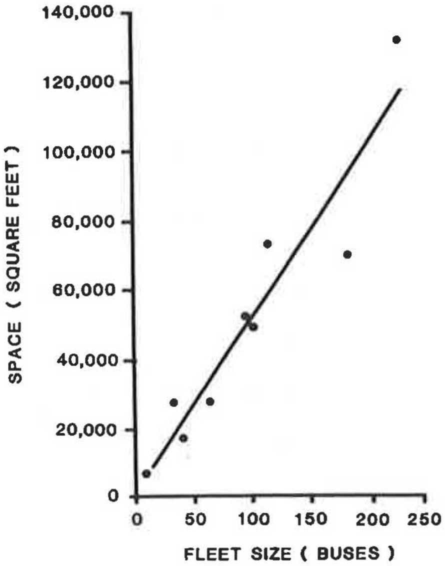


INSPECTION LANE REGRESSION EQUATION

y = 0.045x +	0.667	
(0.010)	(0.393)	STANDARD ERROR OF REGRESSION COEFFICIENT
(4.64)	(1.70)	T-VALUE
(0.00)	(0.05)	SIGNIFICANCE OF T-VALUE
r^2 = 0.51		NUMBER OF CASES = 23

x = ANNUAL VEHICLE MILES IN 100,000'S
y = NUMBER OF INSPECTION LANES

FIGURE 7 Inspection lane area analysis.



INTERIOR PARKING SPACE REGRESSION EQUATION

```
y = 496x  +  2665
    (59)     (1160)   STANDARD ERROR OF
                      REGRESSION COEFFICIENT
    (8.35)   (2.30)   T-VALUE
    (0.00)   (0.03)   SIGNIFICANCE OF T-VALUE
    r2 = 0.91         NUMBER OF CASES = 9
    x = ANNUAL VEHICLE MILES IN 100,000'S
    y = INTERIOR PARKING SPACE IN SQUARE FEET
```

FIGURE 8 Indoor vehicle storage analysis.

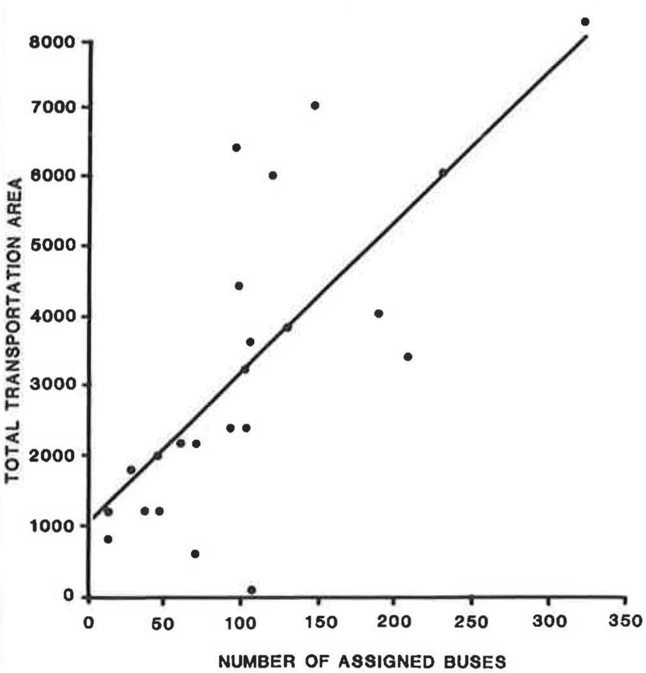
was found to be a good estimator of transportation space allocation (Figure 9). The regression equation calculated from the data suggests a minimum of 900 ft^2 plus 22 ft^2 additional per bus in the active fleet.

As shown in Figure 9, there is variation from the regression line on both the high and the low sides. This may be the result of differences in driver amenity policies. Some transit systems have relatively austere facilities for drivers, whereas others provide exercise rooms, large dayrooms, snack rooms, and so on.

OFFICE SPACE

More office space for administrative functions is provided in transit systems with only a single maintenance facility than in systems with multiple facilities. An average of 7,100 ft^2 of administrative space was provided in single-facility systems, whereas only 1,900 ft^2 was provided in multiple-facility systems. The reason for this difference is that multiple-facility systems are more likely than single-facility systems to maintain separate administrative offices away from the maintenance facility.

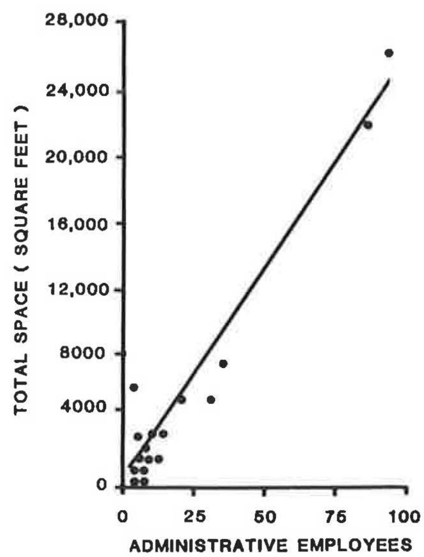
Although the gross amount of administrative space differed between the two system types, there was no difference in the amount of space that was provided per administrative employee. Approximately 260 ft^2 per administrative employee was provided in both single- and multiple-facility systems. The use of administrative employees as the independent variable was found to provide the best statistical relationship for administrative space (Figure 10).



TRANSPORTATION SPACE REGRESSION EQUATION

```
y = 22x  +  938
    (4)     (553)     STANDARD ERROR OF
                      REGRESSION COEFFICIENT
    (5.18)  (1.70)    T-VALUE
    (0.00)  (0.05)    SIGNIFICANCE OF T-VALUE
    r2 = 0.56         NUMBER OF CASES = 23
    x = ANNUAL VEHICLE MILES IN 100,000'S
    y = TRANSPORTATION SPACE IN SQUARE FEET
```

FIGURE 9 Transportation space analysis.



TOTAL ADMINISTRATIVE SPACE REGRESSION EQUATION

```
y = 258x  +  752
    (15)      (460)    STANDARD ERROR OF
                       REGRESSION COEFFICIENT
    (17.15)  (1.64)    T-VALUE
    (0.00)   (0.06)    SIGNIFICANCE OF T-VALUE
    r2 = 0.94          NUMBER OF CASES = 20
    x = ANNUAL VEHICLE MILES IN 100,000'S
    y = TOTAL ADMINISTRATIVE SPACE IN
        SQUARE FEET
```

FIGURE 10 Administrative space analysis: all facilities.

TABLE 2 Summary of Space Guidelines for Transit Maintenance Facilities

Functional Area	Space Allocation (ft^2) Single-Facility Systems	Multiple-Facility Systems	All Systems
Maintenance			
Maintenance bays			250 x VMT
Parts storage	233 x VMT	126 x VMT	
Other storage	52 x VMT		
Tire shop			
With bay			2,141[a]
Without bay			517[a]
Brake shop			
With bay			1,600[a]
Without bay			330[a]
Battery room			235
Body shop			2,835
Dynamometer bay			1,719
Electrical shop			291
Injector repair shop			187
Overhaul shop			2,324
Paint shop			2,037
Parts cleaning area			500
Steam cleaning area			1,148
Bus servicing			
Daily servicing			99 x bus
Vehicle inspection			0.667 lane per VMT
Interior parking			496 x bus + 2,665
Transportation			22 x bus + 938
Administration			258 x ADEMP

Note: VMT = annual vehicle miles (100,000s); BUS = number of buses in the active fleet; ADEMP = number of administrative employees.

[a]Some shops include a bus bay; others do not.

CONCLUSION

The state-of-the-practice data presented in this paper reflect the design decisions of many architects and bus maintenance engineers that have bee incorporated into facility designs. It was not pos sible to totally reconstruct the planning proces for the facilities in the sample, because the personnel responsible are often no longer with th system or the details of planning are forgotten. Th approach of this research effort was to construct composite planning guideline by observing what wa actually built and relating that to the condition of operation. Table 2 summarizes the key space-allocation findings.

These space-allocation guidelines are not intended to replace the planning and design role o architects and local maintenance managers. Rathe the guidelines provide both a starting point fo space-allocation planning, to be refined accordin to local conditions, and a final check to see whether a new design is more or less in line with what other systems have done.

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Impact of System and Management Factors on Bus Maintenance

JAMES F. FOERSTER, CLAIRE McKNIGHT, and MARIA KOSINSKI

ABSTRACT

Regression analysis was used to develop models of the reliability and maintenance labor statistics reported by 111 U.S. transit systems. Eight bus systems were selected for intensive analysis on the basis of deviations from the expected pattern of performance. Detailed site visits were conducted to identify local factors that were responsible for the deviations. Comparisons of the site-visit case studies identified several factors that had significant effects on performance. These included tracking and periodic evaluation of maintenance outcomes, driver involvement in prerun inspections, cooperative worker-manager relationships, and avoidance of excessively diverse fleets. A summary of productive management actions was constructed by synthesizing the approaches used at selected case study systems.

Transit maintenance has recently become a subject of considerable interest among researchers, transit managers, and government officials. Two recent TRB workshops have highlighted the importance and complexity of factors that influence maintenance performance. The first, held in 1982 (1), surveyed a number of perspectives on transit maintenance performance, including management structures and skills, use of analytical methods, personnel, recruitment, training and testing, and equipment, facility, and vehicle design. A second workshop, held in 1984 (2), focused on vehicle subsystem improvements. Each of these workshops illustrated the myriad problems encountered in maintenance and suggested a number of appropriate solutions.

The growing interest in maintenance shown by these workshops reflects an increasing concern about maintenance costs and vehicle reliability. Etschmaier (3) has previously documented the rather large amount of intersystem variation in these parameters. Further attention to maintenance has been generated by a recent General Accounting Office report (4) that highlighted apparently pervasive departures from mileage-based preventive maintenance schedules by a number of U.S. transit systems.

A review of the wide range of factors that influence maintenance performance is provided. The review is based primarily on eight case study systems that were selected from among 111 systems included in the data reported for 1981 according to the requirements of Section 15 of the Urban Mass Transportation Act of 1964 (5) on the basis of their roadcall records and labor-hour commitment to maintenance. The purpose of this paper is to illustrate differences among these systems and to identify factors that appear to differentiate between various levels of maintenance performance. The methodological approach used in this effort is that of the comparative case study. This method is particularly well suited to the subject of transit maintenance because it seeks to identify idiosyncratic sources of variation. This is consistent with the often-heard opinion that each transit system is unique, so one system cannot be compared with any other.

The remainder of this paper contains a first-level analysis of Section 15 maintenance data to illustrate how selected factors affect maintenance performance, a description of the rationale used to identify eight systems for intensive case analysis, a report of the results of these case studies, and a set of recommendations based on a synthesis of beneficial practices identified in the system studied.

METHODOLOGY

The approach taken in this research was based on the premise that a descriptive body of information on current industry practice is needed to identify practices that promote efficiency in bus maintenance. The method of comparative case study was selected for this purpose. This method involves the selection of key sites for intensive study on the basis of their departures from expected levels of performance. The unique characteristic of this method is that its focus on departures from expected performance maximizes the likelihood of identifying sources of variation that are not generally recognized in theory or conventional belief. As a result, this method is likely to generate new insights and identify approaches that have potential for improving performance if transferred to other locations.

Implementation of the case study approach involved seven steps. These were

1. Development of a set of initial research issues to be investigated in site visits,
2. Development of field-work procedures for use in the site visits,
3. Establishment of a database containing readily available information about transit maintenance,
4. Calibration of statistical models of observed maintenance performance and identification of systems that showed significant departures from expected performance,
5. Conduct of site visits to outlier agencies,
6. Documentation of site-visit findings, and
7. Cross-system analysis of similarities and differences between agencies.

The research issues identified before initiation of the field work included concerns about system management and labor, local operating environment, budget levels, and physical facilities. These issues were developed into 18 specific hypotheses about the characteristics of maintenance organizations. The details of these hypotheses and the results generated in their evaluation are given in the project report (6).

The site-visit methodology was developed around a set of 11 interview schedules that addressed the issue topics just listed. These forms contained questions and lists of information to be collected during site visits. The interview questions were purposely designed to provide overlap so that the same questions would be asked of a number of persons in different positions to permit validation of answers and analysis of conflicting opinions. Initial drafts of these questions and lists were reviewed with local transit managers and revised to incorporate suggestions about content, wording, and form. The final instrument included questions for persons at all levels of management, including the general manager, maintenance manager, purchasing director, head of operations, garage manager, mechanic, and union representative.

The information base developed for site selection was drawn from Section 15 operating reports and American Public Transit Association (APTA) fleet information listings. It included roadcalls due to mechanical failures, total labor hours for inspection and maintenance, fleet size, vehicle type, percent of vehicles with air conditioning, fleet age, average vehicle speed, peak-to-base ratio, spare ratio, and average vehicle utilization. This database was screened to eliminate systems with rail service and also to exclude systems with more than 1,000 or fewer than 45 vehicles. The decision to focus on moderate-sized systems was based on the desire to address the types of systems most commonly found throughout the United States, and the decision to delete systems with diverse service types was made to avoid problems with the allocation of joint costs.

Regression analysis was used to develop predictive models of roadcall and labor-hour utilization for the 111 systems that met the foregoing criteria. Residuals from these models were then plotted against one another to develop a display of deviations from the expected patterns of performance. Inspection of these plots identified those systems that departed significantly from expected patterns. The most obvious outliers were subject to more extensive analyses, which included reviews of fleet composition, air conditioning equipment, and consistency of Section 15 data from 1979 to 1981.

These procedures resulted in the identification of systems with the following characteristics:

- Three systems with lower-than-average roadcall rates and lower-than-expected maintenance labor requirements (fleet sizes approximately 100, 200, and 700 vehicles);
- Three systems with higher-than-expected roadcall rates and higher-than-average labor requirements (fleet sizes approximately 100, 200, and 700 vehicles); and
- Two systems with lower-than-expected roadcall rates and higher-than-expected labor input requirements (fleet sizes approximately 150 and 500 vehicles).

Each of the sites identified in this way was studied in a similar manner. This involved mailing a letter of introduction explaining the purposes of the research and requesting permission to conduct a site visit, traveling to the site to conduct personal interviews and collect necessary data forms and sample management reports, drafting a report summarizing the findings of the site visit, and reviewing the report by agency management.

Each site visit was conducted in a somewhat different format from that developed in the planning of the study because of system preferences, but all were judged to have generated a sufficient amount of information to be included in the subsequent analysis of intersystem differences. Each site visit was documented in a uniform format to provide information for use in subsequent stages of the research (7-14).

Three different approaches were used in analyzing the information gathered in the case studies. The first consisted of a close reading of each case and the development of summaries addressing each of the issue topics previously identified. These summaries were condensed into exhibits highlighting the most notable features of each system. The second analytical step was to relate each of the conditions observed in the site visit to system performance characteristics as defined by deviations from expected roadcall and labor requirements. The third step was to combine these observations into a summary of the conditions and practices that appeared to account for maintenance performance at the systems in question.

PRELIMINARY SITE SELECTION RESULTS

The regression analyses used to develop predictive models of roadcalls and labor utilization were the result of extensive analysis of the Section 15 data. The criteria used for model development included correctness and significance of coefficient signs and overall r^2 values.

The best models identified were as follows:

$$RC = -0.802 + 0.114*\log(VEH) + 8.905/SPEED \quad (1)$$

$$LH = -2.9 + 0.009*VEH + 288/SPEED + 0.8*AGE + 9.3*RC - 6.1*SPARE \quad (2)$$

where

RC = roadcalls due to mechanical failure per 1,000 revenue miles,
VEH = number of revenue vehicles,
SPEED = average speed (mph),
LH = ratio of maintenance labor hours to revenue miles,
AGE = mean fleet age, and
SPARE = ratio of revenue vehicles to peak vehicles.

These models were found to be statistically significant, but they do not account for a large percentage of the variation observed in the data. The roadcall model has an r^2 of .17, and the labor model has an r^2 of .39. Both models were significant at the 0.05 level. The individual coefficients of the variables are all significant at the 0.10 level, or better, with the exception of the AGE variable in the labor model; this variable was significant at the 0.12 level.

Speed was the most significant variable in each model. Both labor hours and roadcalls decrease as speed increases. This variable captures, to some extent, the effects of congestion levels and stop-and-go driving conditions on maintenance.

The direct relationship between fleet size and roadcalls and labor requirements may be due to the more severe operating environment found in large systems, but it is also possible that the effect identified represents diseconomies of scale; this interpretation is supported by the finding that speed and system size are not strongly correlated.

Roadcalls are directly related to labor-hour requirements, but it was not possible to produce a significant coefficient for labor in the roadcall model. This can be interpreted as an indication that labor effort, unless properly directed, may not be effective in increasing vehicle reliability. The ratio of revenue vehicles to peak vehicles was significant in the labor-hours model, indicating that higher spare ratios permit more productive use of maintenance labor. Finally, fleet age was found to be positively associated with labor requirements.

The models just presented give some indication of the effect of local factors on maintenance costs and performance, but they cannot be recommended as a way of setting standards or evaluating performance because of their low r^2 values. They should be thought of as a description of existing conditions, and their low r^2 values should be recognized as an indication of the large amount of residual variation left after standard system descriptors have been accounted for. They should not be thought of as production-possibility frontiers or minimum-cost functions.

The regression equations are nevertheless useful as a starting point for identification of systems that exceed or fall below common levels of maintenance performance. Figure 1 shows how the models were used to select case systems for intensive study. The observed labor input to the maintenance and roadcall record and the values expected on the basis of regression analyses are shown as vectors. The tails of the vectors are the values expected on the basis of the regression models, and the heads indicate observed values. The length of the vectors represents the difference between the expected and observed values. The specification of the regression models allows the interpretation of the location of the tails of the vectors as the result of service profile severity and diseconomies of scale (for roadcalls) as well as fleet age, in-service breakdowns, and spares (for labor hours). The direction in which each vector points indicates how much better (or worse) than expected each system performs. Short residual vectors indicate little variation from the expected pattern, whereas longer vectors are a sign of significant departures from expected performance. Vectors pointing upward indicate that the system has a higher-than-expected roadcall record; vectors pointing to the right indicate that the system has greater-than-expected labor requirements.

The pattern of residuals shown in Figure 1 is that of the eight systems (A-H) selected for intensive on-site analysis. The configuration of the residual vectors raises questions about why five of the systems differ along the dimension of a low ratio of roadcalls to labor versus a high ratio of roadcalls to labor and why two of the systems appear to have higher-than-expected labor requirements and lower-than-expected roadcall records.

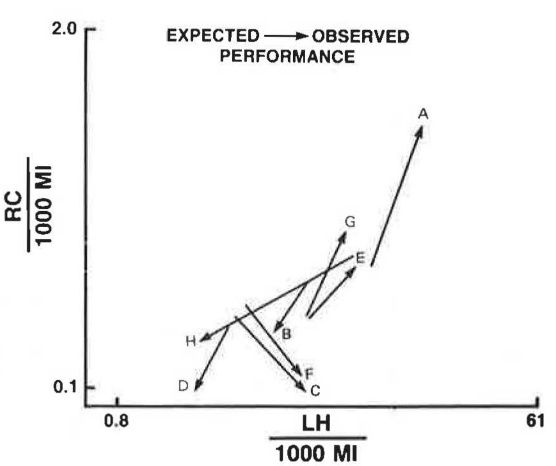

FIGURE 1 Residual variation to be explained in case analysis.

CASE COMPARISON RESULTS

Analysis of the eight case studies identified a number of practices that have a positive influence on maintenance; it also uncovered a number of problem areas. Table 1 summarizes the major factors identified in the field-work phase of the research and indexes these practices and problems to the positions of the residual vectors (A-H) in Figure 1. Footnoted items were not in place in 1981, the year the data used in these regression analyses were collected. These results are summarized in the following discussion.

Management Issues

Few of the systems visited showed any strain in the relationships between managing directors and maintenance managers. Some of the systems depended on formal, regularly scheduled meetings, and others depended on frequent informal discussions. System A reported a long history of management transitions that had interfered with communications and, in fact, had led to a serious failure of the system's inventory control system. In this system, as well as in others, steps had been taken to improve this situation. The approaches identified included formal management-by-objectives systems as well as highly interactive team-management approaches.

In every system visited it was indicated that the goals of minimizing costs and maximizing in-service reliability were endorsed. Some of the systems had written policies and rules for setting maintenance priorities, whereas others said that they relied on tradition and informal understandings. In many systems preventive maintenance (PM) schedules were the only written policy documents in existence. The existence or lack of written understandings about maintenance priorities does not have a simple relationship to system performance. Both the best and the worst systems (in terms of Figure 1) had little in the way of documentation of maintenance priorities. The important factor appears to be whether policies (written or unwritten) are known to all levels of management and whether management periodically reviews and revises these policies in response to local conditions. Systems reporting that they informally or formally review maintenance priorities on a regular basis consistently had fewer roadcalls than those systems with no tradition of self-evaluation and policy review. Those systems with the tradition of setting reasonable performance goals and tracking actual performance were generally among the better performers than systems with little maintenance accountability.

This review of preventive maintenance practices generated interesting results regarding the philosophy of preventive maintenance. Previous research (6) has indicated that there is extensive literature on mileage-based maintenance and unit exchange. Much less attention has been given to the practice of maintenance by monitoring, except for the work of Etschmaier (3), who has argued that resources can most effectively be utilized by monitoring vehicle condition instead of focusing on intensive mileage-based inspection and replacement. The field data collected did not show a strong relationship between

TABLE 1 Summary of Case Analysis

System	Positive Factors Influencing Maintenance	Problem Sources
A	New management system (MBO)[a]	Understaffing due to hiring freeze and loss to other firms
	Performance targeting[a]	History of transitions and reorganization
	Mechanic training program	No driver inspections
	Testing program	Inventory management
	Refresher courses	Adversarial labor relations
		Low salary levels
		Diverse fleet
		Climate and air conditioning
		High load factor
		High overtime utilization
		Lift orientation in garages
		Relationship to county
B	Stable management	Lack of written procedure
	Good, informal management process	Older fleet
	Performance trend analysis	Old garage and shop built for streetcars
	Oil analysis[a]	
	Dynamometer	
	Prerun inspections	
	Good worker input to management	
	Mechanic training program[a]	
	Testing for hiring and promotion	
	Relatively uniform fleet	
C	Stable, experienced management	Climate and air conditioning
	Written rules and procedures	
	Performance trend analysis	
	Prerun and postrun inspections	
	In-house shop capabilities	
	Vigorous use of probationary period	
	Uniform fleet	
	Air conditioner retrofit program	
	Low load factor	
	Extensive in-house shop facilities	
D	Weekly management staff meetings	Staff position shortages
	Performance trend analysis	Cold weather and outdoor storage
	Prerun and postrun inspections	Lift capacity for RTS
	Worker suggestions implemented	Transmission failures
	Uniform fleet	
	Positive management-staff relations	
	Budget security	
	New garage	
E	Management by objective system[a]	Poor enforcement of prerun and postrun inspections
	Performance trend analysis and targeting[a]	Undifferentiated bi-monthly maintenance program
	High salary levels	Old (14.5 yr avg) fleet
	Apprenticeship program[a]	Terrain
	Transmission ratio modifications	Inadequate garage
F	Team management system	Old system of eight garages (recently replaced)
	Performance trend monitoring and targeting	
	Supportive board	
	Prerun and postrun inspections	
	New computer record system[a]	
	Frequent labor-management meetings	
	Apprenticeship program[a]	
	State-of-the-art garage[a]	
G	Uniform fleet	No trend reporting
	New garage (planned)[a]	No prerun inspections
		Adversarial union relationship
		Low wage structure
		Low number of mechanics and high overtime
		No formal testing
		City snow removal
		Inadequate inventory and garage space
		Budget not secure
H	Performance targeting and trend analysis	Management style conflicts
	Prerun inspections	Inadequate city snow removal
	Frequent supervisor-mechanic meetings	100-yr-old garage
	High wage rates	Inadequate shop tools
	Testing for hiring and promotion	Inadequate inventory space
	Apprenticeship program[a]	High load factor
	Newer, uniform fleet	
	Good union relations	

Note: RTS = advanced-design bus produced by General Motors Corporation.

[a]Innovations or changes occurring since 1981.

PM intervals and performance, but they graphically indicated that there is a strong correlation between the conduct of prerun and postrun inspections and performance. This finding held for each of the eight case systems. Those that conducted prerun inspections consistently had fewer roadcalls than expected, and those with no prerun checks consistently had more than expected. San Antonio, one of the case study systems, provides a good example of such procedures. Its prerun inspection requires the signature of the driver and, if a defect is reported, that of a maintenance employee. This method of involving both transportation and maintenance establishes accountability for in-service failures. It also prevents roadcalls from drivers who want a replacement vehicle just because of minor problems. (Two of the "poorer" systems visited were in the process of implementing prerun procedures.)

The preceding discussion should not be interpreted as an indication that PM inspections are unnecessary.

TABLE 2 Recruitment Practices

System	Case Study Results
A	Union claims starting salaries too low; superintendent of budget and administration claims testing too stringent; apprenticeship program successfully attracting applicants
B	Normal progression from driver to cleaner to mechanic; some problems in recuitment; apprenticeship program established
C	No problems reported; management selective in hiring (only skilled mechanics considered); many mechanics let go during probation period
D	Normal progression from driver to cleaner to mechanic, but not enough staff being recruited; new contract may change this provision
E	Maintenance manager and personnel officer believe applicants qualified; apprenticeship program being developed
F	Emphasis changed from on-the-job training of unskilled workers to apprenticeship effort drawing on local vocational education program
G	System needs mechanics with better skills in air conditioning and electrical systems
H	No problems cited in hiring qualified mechanics; apprenticeship program developed

Some of the systems had simple bimonthly inspections with no differentiation between major and minor servicing (e.g., System E), and others had elaborate three- and four-level PM programs. The differences between more elaborate programs were not evident, but simple bimonthly programs do not appear to be adequate.

Labor Issues

Several of the case study systems reported adversarial labor-management relationships, and grievance statistics showed this to be the case. However, the relationship between performance and grievance counts was not strong. What was more important as a correlate of performance is the existence and use of formal or informal channels of communication between maintenance workers and management. Productive informal meetings were cited as the norm in the low-roadcall systems, whereas those systems that had roadcall counts above expected levels emphasized only formal channels of communication and gave little indication that these channels were being used effectively.

A number of differences were found in wage rates and mechanic recruitment practices. Differences in recruitment are shown in Table 2. Systems B and D are the only ones that use a progression from driver to cleaner to mechanic, and both of these systems reported that this mechanism was not meeting their labor needs. System C is unique because it hires only skilled mechanics and is selective in retention of employees through the probationary period. The salary levels in Table 3 (15-18) show a wide range of relative and absolute variation. System C, for example, increases mechanics' wages by 44 percent as they move from entry to senior positions, whereas System G shows a 6 percent increment. Evaluation of these wage structures is difficult. Initial comparisons with regional wage levels show that wage rates are not closely tied to local conditions, and some systems are found to be paying senior mechanics much less than the wage rates in other industries. Some attrition was found in systems paying rather high wage rates because of competition from the aircraft and trucking industries for mechanics. The general relationship between performance and compensation indicates that higher mechanics' salaries are related to better performance, except in cities where there is intense competition for mechanics. This suggests a need to find ways of retaining mechanics in these more competitive labor markets.

Testing and training are growing concerns for many transit systems. Most have some sort of testing program for use in screening applicants, but few reported vigorous use of tests in promotion and none reported the use of periodic tests to verify abilities of current staff members. A number of different approaches to training were identified, including the establishment of formal apprenticeship programs, use of community colleges, and provision of optional refresher courses for mechanics.

TABLE 3 Salary Levels *(15-18)*

	Wage ($/hr)		
System	Entry Level	Top Level (nonsupervisory)	Percent Increment
A	8.46[a]	9.75[a]	25
B	9.95[b]	12.48[a]	25
C	6.50[a]	9.40[a]	44
D	9.52[a]	11.20[a]	17
E	9.25[b]	13.00[a]	40
F	7.27[b]	9.52[a]	30
G	9.24[b]	9.88[b]	6
H	11.11[a]	12.27[a]	10

Note: Wages for maintenance workers from APTA *(15-17)*. Average wages from Bureau of Labor Statistics *(18)*.

[a]Wage rate for maintenance worker is greater than the average wage rate for production workers in manufacturing for the region.

[b]Maintenance worker's wage rate is less than the average.

Fleet Composition and Local Environmental Conditions

Vehicle age and fleet mix were obvious contributors to differences in system performance. System H had the newest and most uniform fleet in 1981; all the vehicles were from General Motors. Since then, a number of other vehicle types have been added. This has increased the complexity of the inventory significantly and created problems in procurement. Many of the parts in the inventory are double stocked under different identification codes. At other systems, fleet factors were linked to performance differences. For example, System A had the most diverse fleet in this sample, which resulted in an inventory of over 9,800 items and space and inventory control problems. On the other hand, System C, with a much more uniform fleet, had no space problems and a time-tested manual inventory control system.

Not surprisingly, all of the case study systems reported that fleet age and climate were a major influence on maintenance. Systems B and E both cited fleet age as a major cause of maintenance problems, and because their fleets were more than 12 years old, this appears reasonable. However, Systems G and F also reported age-related problems, but their fleets were 9.2 years old, which is near the mean for this sample of systems. Systems A and C reported problems with heat and humidity as did Systems D and H. Surprisingly, not all of these systems had investigated the possibility of installing air conditioner retrofits. Some of the systems appeared to have been quite aggressive in adapting their equipment to local conditions, whereas others had not. System A, for example, was experimenting with air starters, and System E had modified transmission gear ratios to increase power on hills.

Budget

Each of the eight systems studied reported line-item incremental budgeting for maintenance. Unit cost data, it was found, were either nonexistent or not complete enough for use in budgeting. The most aggressive budgeting program had been instituted in System A; this was a long-range budgeting system that would include both annual budgets and long-range capital programming for vehicle acquisition and maintenance facility planning.

Staff perceptions of their budget were not simply related to the amounts of money allocated to maintenance. Table 4 shows budget data for the eight systems. Cost per mile is strongly affected by wage rates because labor and fringe benefits make up about 60 percent of maintenance costs, and so comparisons must be made carefully. System C was notable as having the lowest cost per mile of all the systems in the sample. However, it was only the fifth lowest in terms of the percentage of the operating budget that it allocated to maintenance. This is in part because of low regional wage rates. System G has the second highest cost per mile in the sample. This is remarkable because its management cited staff reductions as a major problem. The relationship between understaffing and costs can be explained by high overtime, which was estimated to have been an average of 20 hr per week in 1981.

TABLE 4 Maintenance Budget *(5)*

System	Maintenance as Percentage of Operating Budget	Maintenance Cost per Revenue Mile (cents/mile)
A	26.2 (8)	60.6 (8)
B	18.0 (2)	40.2 (3)
C	20.0 (5)	31.6 (1)
D	21.1 (6)	32.3 (2)
E	17.7 (1)	49.0 (6)
F	18.7 (4)	44.2 (4)
G	24.1 (7)	58.8 (7)
H	18.3 (3)	45.2 (5)
Median for 111 systems	18.7	40.0

Note: Rank is given in parentheses, 1 being the lowest.

Systems A and G stand in contrast to Systems C and D because of their location on the dimension of a low ratio of roadcalls to cost versus a high ratio of roadcalls to cost in Figure 1. This contrast suggests, and the studies confirmed, that maintenance budgets per se are not the key to improving reliability; this is also evident from the regression models discussed in the previous section. The key difference between these systems appears to be management.

Maintenance Equipment and Facilities

Only a few systems reported major equipment problems. System H noted a need to replace drill presses, lathes, and chain hoists and System B had experienced problems with metric tools, but both planned to remedy these situations in the near future. A larger number of systems reported problems accommodating new vehicles because of size. These had resulted in the need to rely on blocks and portable lifts and, in some cases, to restrict purchases of new vehicles to those that could be handled with current facilities.

Old and inadequate facilities were a special problem in Systems G, H, and E. System G had only two lifts and one pit, and the space problems were so severe that scattered, on-floor storage had to be used for major components, including engines and transmissions. The garage at System H, which was over 100 years old, had layout problems that made supervision difficult and inventory access time-consuming. At System E, the garage was not extremely old, but there was not enough space to handle the current fleet and the lifts could not accommodate the system's newer, larger buses.

A number of new facilities had deficiencies in layout, including lack of space for newer vehicles and test equipment. Many of the systems reported that new garages had failed to reduce roadcall rates as had been hoped but did have a positive effect because there was less absenteeism and better worker morale.

Facility age is not always related to performance. System C showed an excellent performance record despite its 36-year-old garage, and System F reported an excellent reliability record in spite of having eight separate garages for its small (200-vehicle) fleet in 1981 when the initial data were collected. It did expect to gain labor efficiency from a recently completed garage that now houses its entire fleet. Systems D and B also turned in good performance records in spite of older (and now vacated) facilities. Systems H, E, and G, however, were clearly handicapped by their garage problems.

DISCUSSION

A number of practices that have a positive impact on maintenance were identified in this research; a number of problem sources were also documented.

The results regarding day-to-day operations and PM programs are similar to those of previous studies (19-21), which found that the major emphasis was on inspections, adjustments, lubrication, and breakdown maintenance, with less emphasis on cost analysis, use of failure data, and unit exchange planning. These results confirm those of previous studies regarding vehicle design problems, space, budget, and staff levels. They also verify that unit cost and component life statistics are generally not used in planning maintenance programs because the raw data for developing these figures are not available in many systems and, where available, are in forms that are inconvenient to use.

These findings show that prerun inspections are not always carried out by many systems. But more important, it was found that the lack of prerun inspections is highly correlated with vehicle reliability problems because these inspection procedures prevent driver use of roadcalls to obtain bus changes for minor problems and because of the importance of driver inspections in monitoring vehicle condition.

A major difference between these findings and those of earlier studies is that several of the systems in this study had established maintenance performance indicators, tracking systems, and (in some cases) performance targets. Other notable findings were the establishment of formal training programs and testing mechanisms and increased integration of maintenance into budgeting and management decision making. These findings indicate that many of the elements of a strategic planning approach to maintenance (22) are developing. The systems studied illustrate some of the critical elements of this approach to maintenance management.

The need to establish clear, quantifiable goals was indicated by the systems studied. These goals can be stated in terms of locally defined measures of reliability (roadcall definitions still vary greatly from system to system). Goals can also be stated in terms of targeted percentage reductions in roadcalls, budget requirements, and labor intensity. Both cost and reliability goals should be established because there is an implicit, undefined trade-off between reliability and cost involved in maintenance budget decisions. This trade-off should be made explicit in the development of goals and performance targets. A performance tracking and evaluation element should also be part of maintenance management. Tracking systems provide management with a tool for measuring progress toward achievement of stated goals and also motivate employees. Analysis of performance and comparison with stated goals should serve as the core of a yearly assessment of effectiveness.

A need for the development of a maintenance planning cycle was indicated by this study. The following information should be generated in this process:

1. A summary of current fleet composition, a list of expected fleet changes, and a description of anticipated impacts of these changes on staff, facility, and equipment needs;
2. A brief overview of current facilities and shop equipment, a description of deficiencies, and a list of anticipated needs resulting from fleet changes;
3. A list of currently budgeted maintenance staff positions, a review of needs for additional positions and an analysis of reasons for unfilled positions, and a description of the staffing impacts of anticipated fleet changes;
4. A summary of recruitment and training, focusing on reviews of the effectiveness of testing procedures used in hiring and promotion, the adequacy of training given to mechanics responsible for new equipment, and hiring strategies (including experience requirements, wage scales relative to other industries, and alternative training approaches);
5. A summary of the PM program used in the previous year, a list of problems encountered in compliance with this program, and a description of anticipated changes in the PM program;
6. A description of prerun inspection procedures, an assessment of driver compliance and maintenance follow-up, and a statement of changes needed to ensure compliance;
7. A summary of any problems encountered with the inventory system and an analysis of changes needed to accommodate new vehicles, special campaigns, or retrofit programs;
8. An analysis of roadcalls and missed trips to identify causes, directions of trends, and possible remedial actions, as well as an assessment of the effectiveness of strategies adopted as a result of problems encountered in previous years;
9. A comparison of budgeted and actual expenses, an analysis of the reasons for variances, an analysis of the impact of anticipated fleet changes on maintenance budgets, and a projection of next year's budget; and
10. A review of written (or unwritten) policies and procedures, a statement of proposed changes, and an evaluation of the effects of changes made over the past year.

Although this list may seem imposing, this study suggests that systems that engage in this sort of periodic review are likely to have positive performance records.

Several research and technical support needs were suggested by the site visits:

1. There was strong sentiment that a cross-listing of interchangeable parts would reduce inventory space and control problems; this list could take the form of a periodically updated paper list or a computerized cross-reference program;
2. Inventory clerks and managers cited a need for a flexible computerized inventory control system that could accommodate fleet mix changes and automatically cross-reference interchangeable parts; and
3. Technical support for computerization of management information systems was also noted; several sites reported unsuccessful attempts at computerization, and others noted that their staffs need to be educated about the capabilities of computer systems.

Fruitful areas for future research were also suggested by the site visits. The first topic, which has the highest potential immediate payoff, is prerun and postrun inspection procedures. Establishment and enforcement of these procedures were perfectly correlated with the roadcall experience of the systems studied. A study to identify potential barriers to driver involvement in inspections and develop a strategy for introducing this concept in systems that do not currently require inspections is needed.

A second area for research is maintenance inspection and maintenance policy. There were no strong indications that PM intervals were related to performance in the systems studied. It was also found that unit cost and reliability data are not often collected and that the quality of PM work is often suspect. There is therefore little basis in these systems to decide on the appropriate mix of inspections, monitoring, and unit exchange in maintenance. A careful comparison of these methods in an environment that would provide for a fair test of the costs and effectiveness of these maintenance strategies is needed. This environment should include unit-costing and failure-tracking capabilities as well as quality controls on mechanic and driver compliance with inspection and servicing schedules.

A third topic is that of manpower planning. The findings regarding training, testing, and salary levels indicate that practices in these areas are changing, but there is little consistency in the pattern observed. Because of the diversity of approaches taken to recruitment and training and the lack of evaluation mechanisms at the local level, research in this area is especially needed. A related topic is worker-manager communication. The systems studied showed a number of instances in which worker input was useful in developing and evaluating maintenance procedures and a number of rather unproductive, adversarial situations. Ways of improving communication should be identified.

A final research topic is the refinement of maintenance performance models. The regression models used in the site selection procedures had relatively low predictive ability, and these case studies identified a number of factors that should be tested in a formal modeling effort. This would include quantification of climatological variables and prerun inspection procedures, and it might also involve analysis of staffing levels and policies on utilization of old and new vehicles. A time-series analysis of the effects of PM intervals on reliability could also be conducted. These efforts would be useful for future attempts to define the range of resource requirements and performance that can be expected under changing maintenance conditions.

CONCLUSIONS

The experiences of the eight systems reviewed in this study provide ample support for the argument that every system has unique features, which makes it difficult to conduct cross-system comparisons. However, a number of practices have been identified that are typical of successful maintenance operations and that logically should contribute to positive performance gains. These practices are

1. Conduct of prerun and postrun inspections by drivers;
2. Establishment of performance targets, development of performance measures, and periodic performance trend analysis;
3. Development of written statements of (or informal consensus about) maintenance policies and procedures;
4. Coordination of vehicle procurement decisions with inventory planning and staff development activities;
5. Establishment of strategies for recruiting, testing, training, and retraining skilled staff;
6. Establishment of cooperative working relationships between workers and managers;
7. Avoidance of unmanageably diverse fleets; and
8. Periodic performance assessment and evaluation of alternative strategies for improving maintenance effectiveness.

The case studies also led to the definition of a number of research questions. These indicated the need for analysis of the role of drivers in vehicle condition monitoring, evaluation of alternative maintenance policies and PM intervals, and analysis of recruitment, training, and compensation issues.

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Evaluation of Bus Maintenance Operations

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ABSTRACT

A generalized framework is developed to view the transit bus maintenance operation. Environmental and policy factors that influence and constrain the maintenance organization are shown, and then the maintenance function is defined as a set of eight component activities, which include work assignment, maintenance scheduling, workforce development, labor allocation, inventory management, equipment management, information systems, and monitoring and evaluation. Each activity is conceptualized as a spectrum that represents a scale of increasing sophistication and, ultimately, cost. The external factors and maintenance activities are synthesized to represent a composite profile of a bus system's maintenance department. This descriptive framework is used to demonstrate that different levels of activities are appropriate for different sets of external factors. Finally, applications of the framework at the transit-agency level are discussed.

An organized method for defining and reviewing bus maintenance operations of small and medium-sized transit agencies is provided. The framework is intended to assist researchers in identifying areas of maintenance and associated strategies that can be used to improve the effectiveness of bus transit maintenance organization and delivery systems. It also presents transit executives and public officials with a reference framework for discussing ways to allocate limited resources to make their organization's maintenance program more effective than at present.

BACKGROUND

Transit bus maintenance is by nature a highly complicated and irregular activity that often is scheduled around, and determined by, the needs of the entire organization. Because of the basic, fundamental dependence on the maintenance department by other divisions within the transit agency (e.g., operations, marketing, and administration) the maintenance function often must be responsive to immediate needs of the agency.

Although the role of maintenance has always been important to the welfare of the entire transit organization, recently this role has grown in importance. Certain factors account for this growing importance:

- Maintenance activities have been shown to absorb more than 20 percent of annual transit operating expenses, and the proportion appears to be growing (1);
- Federal operating subsidies are diminishing, thereby intensifying the need to control maintenance expenses; and
- Market-oriented trends in bus design have placed a growing burden on the task of maintenance.

Growing awareness and interest in these problems have spurred some recent research, but many needs remain to be addressed. Often maintenance research has been addressed from the viewpoint of maintenance labor--the enumeration of tasks and the description of their proper execution. This approach is exemplified by the many procedural manuals that are available within the industry.

In this paper the maintenance department is first differentiated from other units within a transit agency, and then the key activities of maintenance management are illustrated. Finally, a general model for the analysis of bus maintenance operations is presented.

LITERATURE REVIEW

Recent years have seen an upturn in maintenance research, and as a result, better, more productive maintenance methods should evolve. The body of maintenance research can be characterized by chief subjects of study. Some research (2-4) has been concerned with disseminating exemplary forms and interval schedules for reference. Other studies (5,6) have conducted questionnaire surveys of preferred maintenance practice. Still other studies (7,8, paper by Foerster et al. in this Record) have focused on the intriguing prospects of regression performance models. Perhaps the greatest interest has been directed to analysis of the optimum establishment of intervals and scheduling (9-15). These and other recent studies have done much to improve the status of available literature on maintenance. Generally, a particular subject of interest in maintenance has been isolated and examined in detail.

Unfortunately, although many of the findings have proved to be interesting, there has been difficulty in bridging the gap from research findings to practical implementation. Even if the recommendations are justified, the findings seldom appear easy to incorporate into industry practice. A classic case is the frequent recommendation for agencies to maintain detailed parts histories. This idea appears perfectly sensible to researchers but prohibitively demanding to the industry.

Furthermore, the literature review reveals that bus maintenance research may have neglected to address the need for general education in the industry. In the following cases--an administrator newly arrived to the responsibilities of maintenance, a board member or upper-level administrator who is unfamiliar with the concepts of maintenance, or maintenance laborers who are being trained to view the overall picture of maintenance--the individual in each case should benefit from a general document reviewing maintenance management and placing it in a meaningful context. Scant literature exists to provide a simple, comprehensive overview of the maintenance department and the associated management activities that can be brought to bear on it. This discussion thus proceeds from a perception of a need for such a general document.

INTRODUCTION OF FRAMEWORK

This project is restricted to small to medium-sized agencies, ranging in size from 15 to 500 vehicles. The omission of very small and very large agencies preserves the general applicability of the model, because the extreme sizes frequently employ exceptional administrative arrangements.

In constructing a general maintenance model, the first challenge is to provide a simple, convenient conceptual framework. This framework should assist in placing the maintenance department in the broad context of the transit organization. Second, a useful model should outline key management opportunities--those areas that management can control to achieve maintenance objectives.

The first step of the approach, then, must be the placing of the maintenance department in its context. Maintenance exists alongside other departments. These departments exist within an organization, and this organization is itself contained within a larger community.

Figure 1 demonstrates these contextual relationships. It provides a broad, conceptual flowchart that traces the production of service output through the organizational process. Figure 1 identifies not only the maintenance department and other departments but also those conditions that set the stage for the operations of these departments.

Many important limiting conditions are set before the transit agency ever makes its first decisions. Figure 1 identifies these limiting conditions as community-external constraints. These constraints, which arise outside the maintenance department and outside the transit agency as well, are as follows:

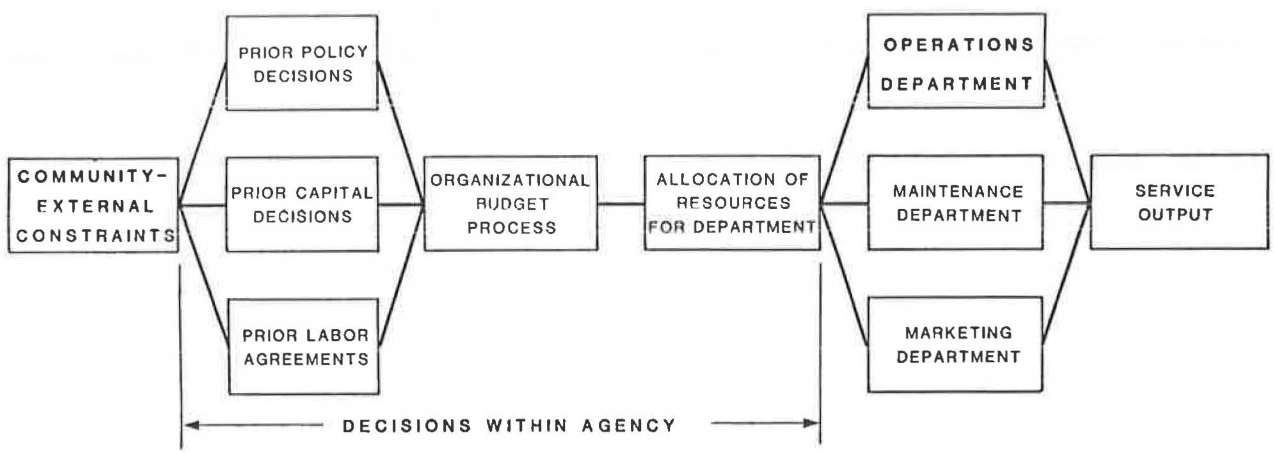
- Community size,
- Community density,
- Community values (transit use, local funding),
- Terrain (flat or hilly),
- Climate (cold or hot, moderate or variable),
- Street conditions (potholes, narrow streets), and
- Local labor market (union climate, high or low wage rates).

Proceeding through Figure 1, many important limits are further set by the decisions of upper transit management. These decisions are made outside the maintenance department but inside the transit agencies. They are as follows:

- Organizational objectives,
- Hours of revenue service,
- Fleet size,
- Fleet composition (type of vehicle, homogeneity of fleet),
- Physical layout of facilities,
- Labor agreements (vague levels, work rules, promotion system, shift restrictions), and
- Budgeting allocations.

For instance, an agency might be described as follows:

- Small community (50,000 population);
- Dispersed community;
- Light transit reliance;
- Flat terrain;
- Warm, moderate climate;
- Inexpensive labor market;
- New road surfaces;
- Fleet of 15 buses;
- Revenue service per week, 72 hr;



*Community-external Conditions (Outside the Agency)
Community Size
Community Density
Community Values (transit use, local funding)
Terrain (flat or hilly)
Climate (cold or hot, moderate or variable)
Street Conditions (potholes, narrow streets)
Local Labor Market (union climate, high or low wage rates)

**Decisions within the Agency (Outside the Maintenance Department)
Organizational Objectives
Hours of Revenue Service
Fleet Size
Fleet Composition (type of vehicle, homogeneity of fleet)
Physical Layout of Facilities
Labor Agreements (vague Levels, work rules, promotion system, shift restrictions)
Budgeting Allocations

FIGURE 1 Determining factors for transit service output.

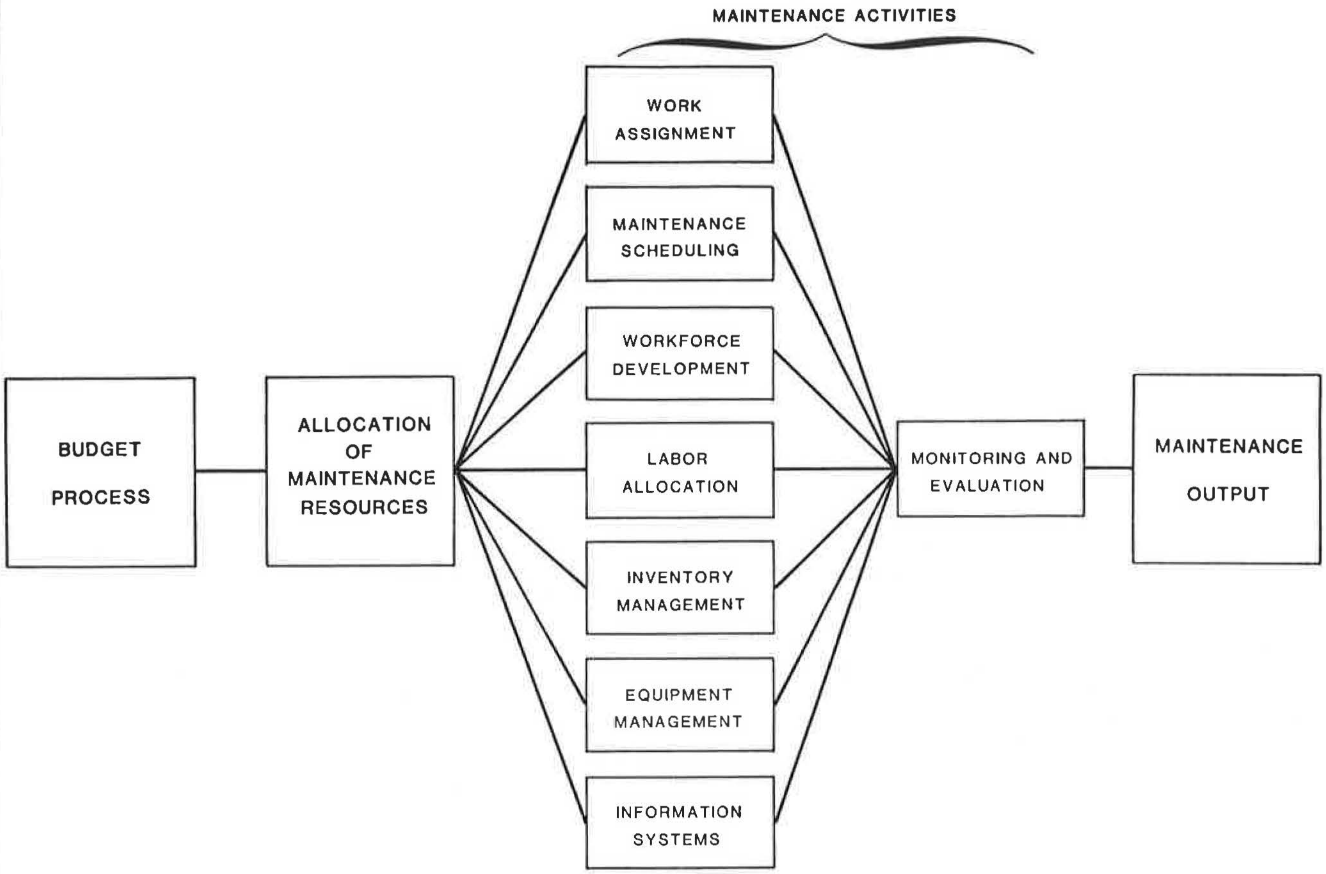


FIGURE 2 Operating activities of the maintenance department.

- Homogeneous fleet;
- Abundant capacity in facility;
- Nonunionized workforce.

None of the foregoing items is under the direct control of the maintenance department, and yet they will play a significant part in the performance of the maintenance department (8).

After a broad organizational overview, it is appropriate to focus on a more detailed analysis of the maintenance department. In Figure 2 this step is outlined by expanding a section of Figure 1. Maintenance is elaborated as a collection of eight activities. It should be noted that in this study the maintenance department is described as a collection of management activities as opposed to the functional description often observed in maintenance (servicing, inspection, repair, etc.). The activities include the following:

- Work assignment
- Maintenance scheduling
- Work force development
- Labor allocation
- Inventory management
- Equipment management
- Information systems
- Monitoring and evaluation

Together, the foregoing activities encompass the total maintenance effort. They can be further broken down into subactivities as will be demonstrated later.

From this preliminary development, a general model begins to suggest itself as shown in Figure 3. By breaking an agency down to key characteristics, it can be neatly summarized into a framework where external factors are set along the left column of a matrix and the different management activities are set along the top row. Given a specific bus system, it and its circumstances can be described in the first column, and the particular strategies of its maintenance department can be entered into the remaining columns.

A number of objectives should be achieved by this framework.

- A convenient method of summarizing different maintenance departments should follow. Such a summary should help to describe an agency quickly, and its format should help to promote comparability among agencies.
- It should be possible to illustrate the relationship of one maintenance activity to another maintenance activity.
- It should be possible to illustrate how different strategies are appropriate for different circumstances.
- A linkage between choice of strategy and output should be demonstrated. The last column of the framework should observe performance measurements. A specific maintenance department should generate its own performance values, and this performance in turn should be related to the strategies chosen in each activity. Although the linkage will not be direct enough to be termed a "predictive" model, it might be termed a "resource performance" model.

EXAMINATION OF ACTIVITIES

The basic framework has now been introduced and the

Descriptors	Work Assignment	Maintenance Scheduling	Workforce Development	Labor Allocation	Inventory Management	Equipment Management	Information Systems	Monitoring & Evaluation
Descriptors of Property A								
Descriptors of Property B								

FIGURE 3 General maintenance evaluation model.

next step is to show how the values are assigned to the different cells. Figures 4-10 follow a two-step format: a recitation of key subactivities and the presentation of the subactivities as a spectrum of strategies. The first seven activities are presented in this format of strategic choice; however, the last activity, monitoring and evaluation, will be presented in the following discussion as a recitation of key measures. (No strategic alternatives are presented for this activity because it will be used to reflect on the other management activities.)

It should be noted that each spectrum is presented as a progression, from a simple case to progressively more complex, developed cases. The strategies are keyed as A, B, C, and D; movement through the alphabet signifies increasing complexity. Thus the letter coding should provide instant identification. When the letter D occurs in a chart, it should instantly communicate a highly developed strategy, even before the reader matches the letter key to its particular strategy on the spectrum.

Monitoring and evaluation departs from the spectrum format of presentation. The following measures are all appropriate for monitoring maintenance:

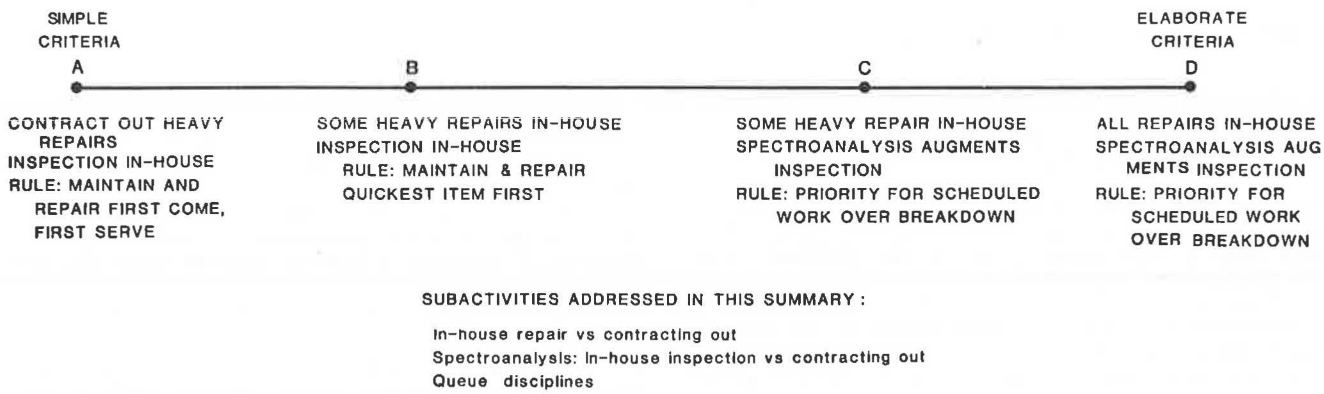


FIGURE 4 Strategic alternatives for work assignment.

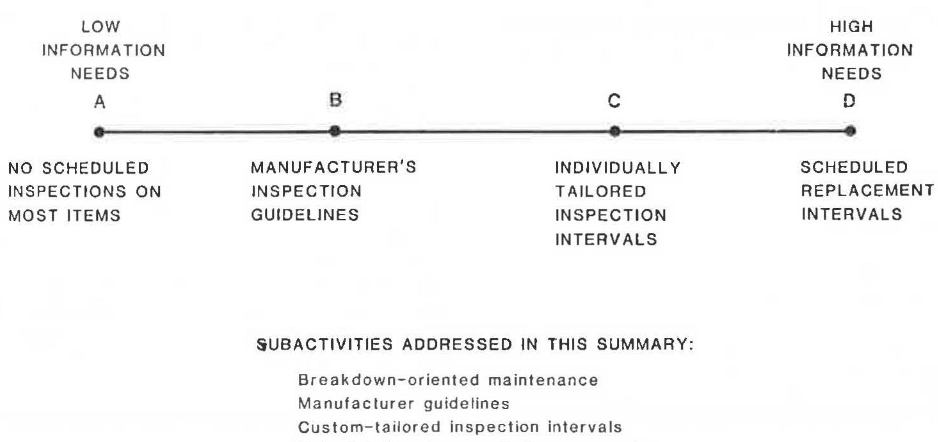


FIGURE 5 Strategic alternatives for maintenance scheduling.

- Roadcalls
- Missed runs
- Late outs
- Inactive buses
- Spare-to-peak-requirement ratio
- Labor-hour productivities
- Life mileage
- Fuel and lubricant use
- Accidents
- Cost of maintenance per mile

However, the measures possess different capabilities. Some reflect only one or a few activities, whereas others reflect the aggregate performance of the department. In this paper two simple measures are ultimately suggested to promote the easiest evaluation of a department: roadcalls and maintenance cost per mile. These are selected primarily on the basis of an adequate quick sketch of departmental performance and availability in Section 15 data, which promotes comparison with other agencies.

USING THE FRAMEWORK

The material necessary to fill the framework is now

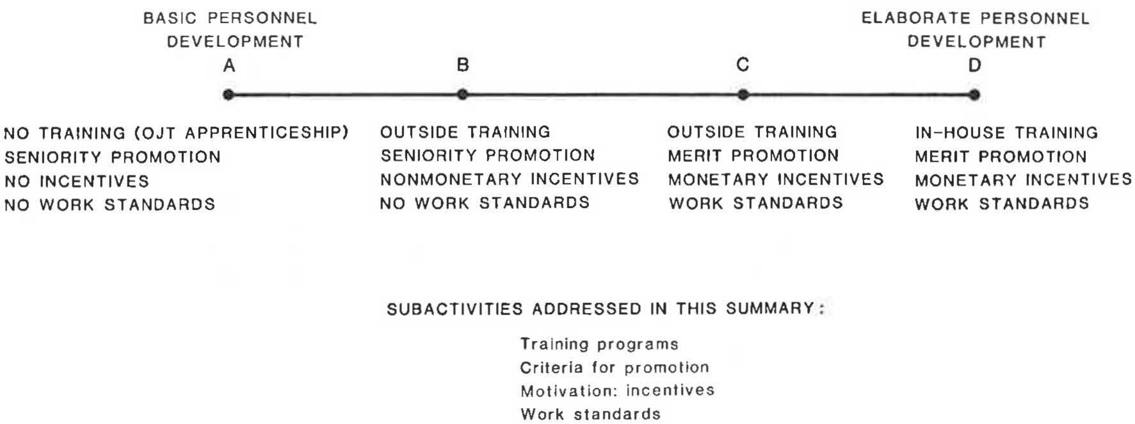


FIGURE 6 Strategic alternatives for workforce development.

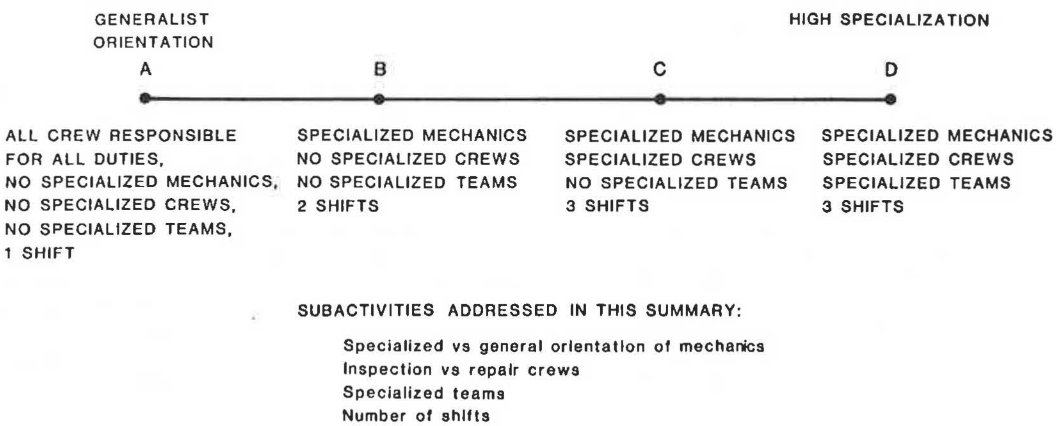


FIGURE 7 Strategic alternatives for labor allocation.

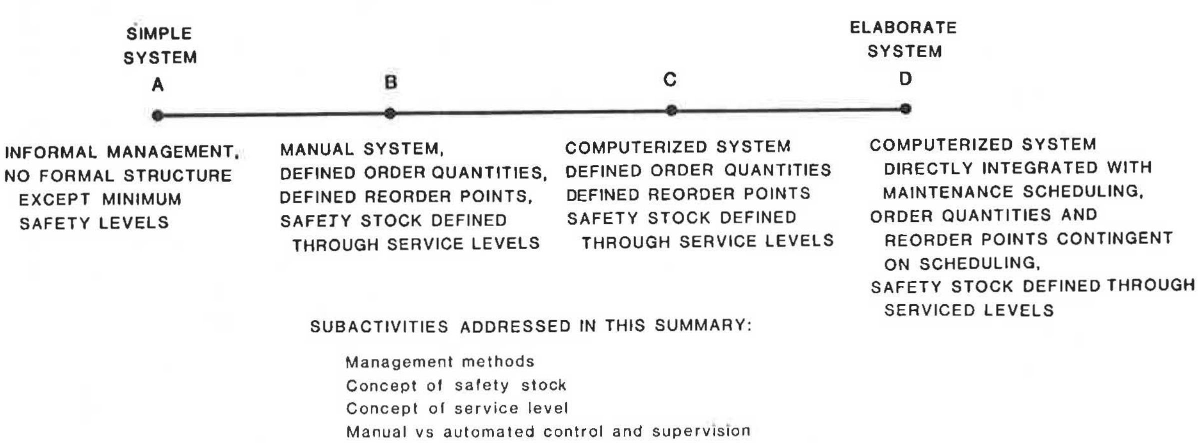


FIGURE 8 Strategic alternatives for inventory management.

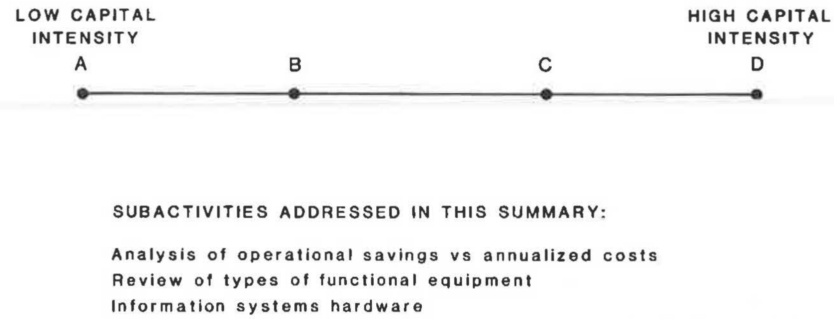


FIGURE 9 Strategic alternatives for equipment management.

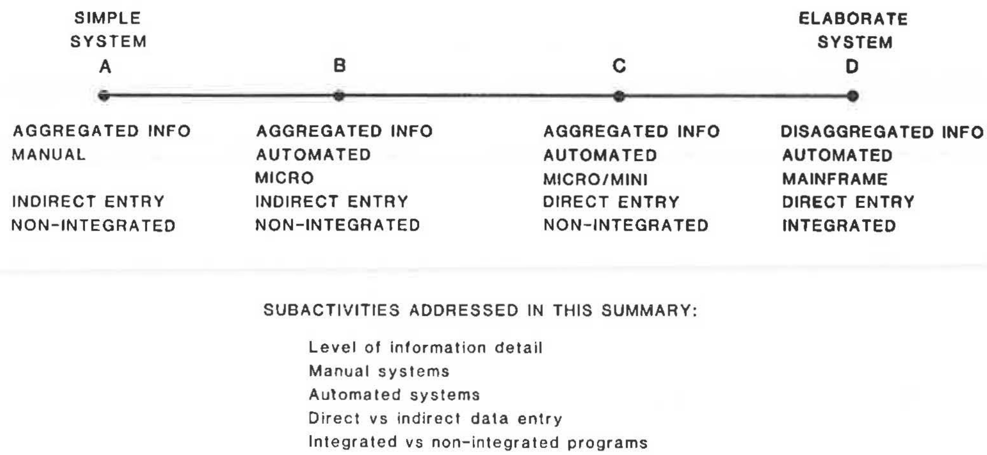


FIGURE 10 Strategic alternatives for information systems.

sufficiently introduced. When external factors (Figure 1) and management activities (Figures 4-10) are combined, they in fact provide a composite profile of a bus agency's maintenance department. Table 1 provides some highly generalized examples of maintenance departments.

Table 1 also provides an opportunity to discuss the framework in its completed form. The external factors describe the particular circumstances of a transit agency. Given a description of an agency's situation, an appropriate selection of strategies (from Figures 4-10) can be lined up. Reading across the row from the description of circumstances, the strategies are explicitly matched to those circumstances. A maintenance department can thus be rendered A-A-A-B-A-C-A or D-C-C-B-C-C-D or B-B-A-B-B-C-C, and so on.

In its complete form, the framework suggests at a glance that some strategies for an activity are consistent with circumstances, and others are not. It stands to reason, for instance, that a large agency with 400 buses would not be a likely situation for A-level strategies, but that it might be suitable for C-level and D-level strategies.

Table 1 also suggests that strategies can be consistent among themselves, or they can be inconsistent. For instance, an orderly arrangement of all A strategies appears consistent internally, but an arrangement of A-A-A-A-A-A-D would appear to support an inconsistent information system strategy.

In these examples, the framework only intends to suggest relationships; further inspection should follow, of course, if action is to be taken by management.

In Table 1, the most visible determinant for the development of a management system is the size of the property--the number of vehicles to be maintained. It is suggested in Table 1 that a small agency with 15 vehicles warrants the simple A-A-A-A-A-A-A configuration, that a moderately small agency with 40 vehicles warrants a B-B-B-B-B-B-B configuration, that a medium-to-large property of 200 vehicles warrants C-C-C-C-C-C-C, and that a large property of 450 vehicles warrants D-D-D-D-D-D-D.

These four general types of departments, then, may provide a basic skeletal reference for this analytical framework--all-A, all-B, all-C, and all-D departments. However, this framework is designed for flexibility, and thus particular details can be incorporated into the analysis, yielding far more than four basic configurations. For example, one might consider how one small change in the description of the base case--say, a hilly operating environment--would alter the proper strategy configuration. Hilly terrain exacts exceptional stress on some components and thus calls for more developed strategies for maintenance scheduling and inventory management. Theoretically, in fact, given four alternatives for each of seven variables, there is a possibility of 16,384 different configurations of strategies--from A-A-A-A-A-A-A to A-A-A-A-A-A-B to A-A-A-A-A-B-B, and so on.

But not all such configurations are valid. In fact, it is the contention of this exercise that some configurations can be recognized as theoretically possible but inherently inconsistent. For instance, the theoretical configuration of A-A-A-A-A-A-D is not practical, because a department with reactive scheduling and minimal information needs for its labor, materials, and equipment management would have no cause to support highly detailed, automated, mainframe integrated information systems.

As a last step in the analysis, some performance evaluation should be applied to the department after

TABLE 1 Composite Profiles of Maintenance Departments

	Maintenance Strategy by Management Activity						
Description (External Factor)	Work Assignment	Maintenance Scheduling	Workforce Development	Labor Allocation	Inventory Management	Equipment Management	Information Systems
[a]Small community (50,000); dispersed community; light transit reliance; flat terrain; warm, moderate climate; inexpensive labor market; new road surfaces; 15-bus fleet; 72 hr of revenue service per week; homogeneous fleet; abundant capacity in facility; nonunionized workforce	A	A or B	A or B	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 hr of revenue service per week; heterogeneous fleet; abundant capacity in facility; unionized workforce	B	B	B	B or C	B or C	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 hr of revenue service per week; heterogeneous fleet; abundant capacity in facility; unionized workforce	C	B or C	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 hr of revenue service per week; heterogeneous fleet; abundant capacity in facility; unionized workforce	D	C or D	D	D	D	D	D

[a]Base case.

it has been entered into the matrix. This study recommends the application of output measures--maintenance cost per vehicle mile and vehicle miles per roadcall--because they provide quick aggregate assessment and facilitate comparability with other agencies. These measures can be compared with Section 15 data, which provide a convenient reference. If the measures appear troublesome (assume that the department's performance is below the average performance for Section 15 agencies in its size bracket), the analyst can direct attention to the configuration of strategies. Irregularities in the configuration may assist in identifying potential causes of poor performance.

The maintenance framework, as exhibited by Table 1, addresses the objectives of this paper. It demonstrates the relationship between diverse elements of the maintenance operation. It underscores the relationship among maintenance strategies and between maintenance strategies and external factors. Last, the framework associates performance measurements with maintenance department profiles. Furthermore, all these objectives can be achieved through easy application.

APPLICATION

A preliminary case study has been conducted as part of the development of the project (16). The maintenance department of an actual transit agency was selected as the subject of the study, and the evaluative framework described in this paper was applied to it. The study method consisted of site visits by the authors, interviews, and the completion of an evaluation form developed from the framework.

The outcome of the study confirmed the utility of the method. The results were consistent with expectations, and the framework was found to greatly assist in the collection of information as well as assist in the analysis of information. Furthermore, the case study data have now been expressed in a format that is readily comparable with that of other transit maintenance departments.

As a result of this application, it is recommended that further case studies be executed so as to develop a basis for comparison among maintenance departments.

CONCLUSIONS

The maintenance management model presented in this paper is recommended for application at the transit agency level. In such application, the model may be employed in many alternative ways. The framework can be used as an introductory descriptive device, or it may be used as an instrument for evaluation of department performance. Furthermore, the framework is adaptable to many procedural approaches. In the simplest form, a quick-response review may be executed by agency personnel. In its most developed form, a formal departmental audit may be conducted by independent experts, relying on evaluation forms, interviews, and site visits.

This effort is seen as one of the early attempts to provide an organized view of the institutional structure through which bus transit maintenance is delivered. There is much opportunity for work in the future to mathematize and computerize the model into a simulation methodology. For example, areas of applied probability and statistics such as regression analysis and reliability models can be employed to show cause-and-effect relationships. Further extensions may include an "expert systems" program for configuring maintenance organizations given certain levels of resources and constraints.

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A Knowledge-Based System for Transit Bus Maintenance

PETER WOOD

ABSTRACT

A knowledge-based system for bus maintenance has the potential for improving the efficiency and effectiveness of bus maintenance by making the knowledge of the most highly skilled maintenance personnel available throughout the transit industry. A knowledge-based system is a practical application of the research that has been performed on artificial intelligence. These systems have been developed for a wide range of applications, including the diagnosis of diesel-electric locomotive problems. The four basic elements of a knowledge-based system are described, and an example is provided of the application of such a system to bus maintenance. From a review of the impact on performance of two other techniques for bus diagnosis, spectrochemical oil analysis and the New York City Transit Authority's Automated Bus Diagnostic System, it is concluded that both a reduction in the time required for diagnosis and an increase in the quality of maintenance, measured in terms of a reduction in road calls, would be achieved. It is recommended that a prototype system be developed so that both the costs of implementation and the savings that would result can be determined.

Effective and efficient maintenance is a key element in the operation of a transit system. Poor maintenance will have an adverse impact on both costs and revenues, because the public has demonstrated quite clearly that reliable service is essential if ridership is to be sustained or increased. Although there has been a considerable improvement over the last decade, the quality of bus maintenance still continues to be a problem. One concern that faces the industry now is one that has faced it for almost two decades--the shortage of adequately trained labor. A combination of unattractive working conditions, uncompetitive salaries, and frequently the requirement that all new employees, irrespective of experience, start at an entry-level position has made it difficult to recruit and employ the highly skilled staff necessary for an efficient maintenance organization.

Many steps have been taken to alleviate this problem. Several transit systems have established training programs to raise the level of performance of their staff. New and improved maintenance manuals have been introduced by both industry suppliers and individual transit systems. Special programs dealing with particular systems such as engines, transmissions, and air conditioning have been sponsored by the American Public Transit Association (APTA). UMTA's Technical Assistance Program has made a wealth of material available to the transit industry. TRB also has sponsored meetings on maintenance research and development and effective tools and techniques (1-2).

One common issue that pervades all the discussions on maintenance needs has been that of better information exchange. In spite of the efforts that have been made to date, there is a general feeling that better information exchange would improve the effectiveness of maintenance. In this paper an approach to information exchange is discussed that combines the latest in computer techniques with the most expert knowledge of maintenance procedures that exists within the industry.

Expert, or knowledge-based, systems are a branch of artificial intelligence. They are now being used in many applications to facilitate the transfer and use of expertise that has been built up over a period of years by one or more highly qualified practitioners. Only recently, the use of an expert system to assist in the diagnosis of diesel locomotive problems was announced. The question that needs to be answered is whether there is any role for this approach in the area of transit bus maintenance.

COST OF BUS MAINTENANCE

The costs of maintaining a bus are difficult to establish, because virtually every transit system has a different basis for allocating costs. APTA has indicated that vehicle maintenance expense for all modes of transit is in excess of $1.1 billion a year, or approximately 19 percent of the total cost of operations. Of this sum, more than one-half is attributed to wages (3). In a more detailed analysis by Etschmaier (4) devoted to bus operations, vehicle maintenance was found to cost $0.526 per vehicle mile. This is close to 20 percent of the average cost per mile for bus operations and amounts to $16,400 per vehicle per year. Etschmaier compared this with a maintenance cost of between $2,100 and $3,000 per year for trucks. The comparative annual mileages were 31,200 for buses and 44,000 for trucks. Although the differences in the operating profiles for the two types of vehicles limit the value of any further comparison between their maintenance costs, this comparison suggests that there is room for improvement in bus maintenance efficiency.

One measure of performance that provides an indication of the effectiveness with which bus maintenance is being performed is the number of road calls that occurs. Again, precise comparisons between transit systems are difficult because of the different definitions used by each transit agency. However, data prepared by APTA (5), shown in Table 1, clearly reveal the great differences that occur between agencies in the number of road calls experienced. The lowest mileage reported between road calls for mechanical failures is 672 miles--about once a week. The median values range between about 2,500 and 3,700 miles (around once a month), whereas the highest mileage reported is about 38,000 miles--less than once a year. Although the 60:1 range of

TABLE 1 Miles Between Road Calls

Population of City	Lowest	Median	Highest
Less than 200,000	1,522	3,116	25,707
200,000-500,000	750	3,701	10,257
500,000-1,000,000	1,294	2,488	28,920
More than 1,000,000	672	2,665	7,652

mileages is undoubtedly due to the differences used for defining a road call, it is obvious that there is a big difference between the lowest and the highest mileages that are being achieved at this time.

Road calls are a particularly appropriate measure of the quality of maintenance because each road call represents an unscheduled activity and frequently an interruption of service. On the one hand, there is an unnecessary expense, on the other, a failure to provide a reliable service. Both have an adverse effect on the transit system. Although a dollar value can be expressed for the cost of a road call (even though it is difficult to find a transit system that can report what the cost is), it is more difficult to express the adverse impact on transit revenues of unreliable operation. Because of this, frequently a comparison is only made between the costs of road calls versus the additional maintenance costs that could be incurred in an attempt to reduce them. Obviously some balance must be maintained. The costs of maintenance of a system that prided itself on having no road calls would probably be so high as to make the size of subsidy necessary to cover the costs completely unacceptable. On the other hand, a system that did the absolute minimum of maintenance and was prepared to accept a large number of road calls would offer such a poor level of service that it would be completely unacceptable to the public.

What would be desirable would be an approach that would result in a reduction in road calls without an increase in maintenance costs. This is what the transit industry is doing in its current efforts to improve the quality of its workforce through improved training. A knowledge-based system is an attempt to improve the quality of work performed by the existing labor force by making the knowledge of the most experienced maintenance staff immediately available. All skills are, by and large, the result of the transfer of knowledge. A knowledge-based system uses modern computer technology to facilitate this process.

FUNDAMENTALS OF A KNOWLEDGE-BASED SYSTEM

A knowledge-based system is a practical application of the research that has been performed over the last 20 or more years on artificial intelligence. Although knowledge-based systems use sophisticated computer and programming techniques, it should be made clear that the power of a such a system lies in the knowledge that it contains rather than in the hardware and software that make that knowledge available.

The history of knowledge-based systems dates back more than 20 years, but it is only in the last decade that they have been considered for general use. Systems are now being used in a wide range of applications, varying from the diagnosis of internal diseases to the configuration of computer systems. Other applications include air traffic control, simplification of symbolic mathematical expressions, and detection of geological deposits. More relevant to our immediate concern, General Electric Company is using a knowledge-based system to diagnose faults in diesel electric locomotives (6). Recently, General Motors invested in one of the leading companies engaged in the development of knowledge-based systems, so it is likely that in the future this approach will be applied to automotive diagnostics.

At one time it was assumed that the ability of a computer to calculate at a high speed would allow problems to be solved by a process of evaluating all the possible alternative solutions. It soon became apparent that the combinatorial explosion of possibilities that arose with even the simplest of problems made this approach completely impractical. At the same time, these problems were being solved on a daily basis. The game of chess is computed to have 10^{120} possible solutions, and yet chess players of all levels play and win each day. The answer to this apparent paradox is the introduction of heuristic rules, or rules of thumb, that human experts have developed to solve such problems. A simple chess problem such as knight and king against rook and king has roughly 20 million possible configurations. Michie has shown that only 30 heuristic rules are necessary to achieve expert performance in solving such a problem (7).

The use of heuristic rules is the basis of a knowledge-based system. As Feigenbaum, one of the pioneers in knowledge based systems, states (8):

> An expert system is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution....
>
> The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed on by experts in a field. The "heuristics" are mostly private, little discussed rules of good judgement that characterize expert level decision making in the field.

A knowledge-based system manipulates symbols rather than numerical values. Because of this, programs are generally written in LISt Processing language (LISP). A number of higher-level languages have been written that facilitate building a knowledge-based system, including EMYCIN, produced by Stanford University, and ROSIE, by the Rand Corporation. Many other programming systems have been developed by private industry.

Figure 1 shows the basic structure of a knowledge-based or "expert" system. It is made up of four major elements:

- A knowledge base--the "facts" referred to by Feigenbaum,
- An inference engine--the "heuristics,"
- A control section for handling the overall operation, and
- An input-output section for communication with the user--generally in regular English.

The knowledge base contains the basic data regarding the topic that is the subject of the expert system. For example, if the expert system was concerned with diagnosis of faulty engines, the knowledge base would contain such data as the number of cylinders for a particular class of engine, nominal pressure measurements, idling speed, injector settings, and so forth.

The inference engine contains a set of rules that it has been determined are used by the expert when dealing with his area of expertise. These are ar-

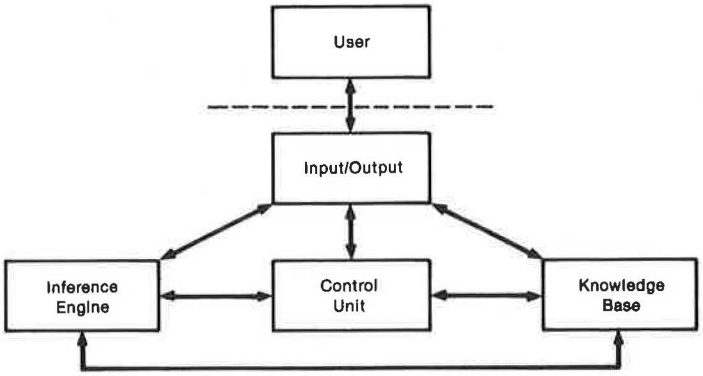

FIGURE 1 Knowledge-based system.

ranged to be encoded in a form IF [conditions] THEN [actions]. A simple example for a gasoline engine would be

> IF [the engine does not start] AND [the starter turns the engine] AND [the fuel gage does not show EMPTY] AND [the accelerator pedal has been depressed several times], THEN the engine has been flooded. The accelerator must be depressed fully and held down while the engine is started. Release the accelerator once the engine fires.

The control section is responsible for controlling the strategy to be used by the system.

Two basic strategies of problem solving are used by knowledge-based systems--data driven (or forward chaining) and goal driven (or backward chaining). The first approach starts with the initial set of data and examines the most likely alternatives. Where additional data are required to resolve an ambiguity, the user is requested to provide the necessary information. In the ideal case, a unique solution is obtained for a given set of data.

The goal-driven approach starts by assuming a certain solution and then works back to determine whether all the data are consistent with this solution. When an item of data is detected that renders the initial hypothesis invalid, an alternative solution is investigated.

In practice many complex systems rely on both approaches. This is particularly helpful when the data are inadequate. A combination of data- and goal-driven search is used, and the approach that most nearly provides a direct and unambiguous connection between data and solution is considered to be the most probable.

Knowledge-based systems have a number of characteristics that make them particularly suitable for applications such as maintenance diagnostics. One of these is the ability to operate successfully in the presence of data that are incomplete or imprecise or both. There does not have to be a complete and unambiguous path from the data to the solution.

Knowledge-based systems also have the capability to explain the reasoning that led to the preferred solution and indicate the probability that it is the correct one. It is accepted that a system will not always provide the correct answer (its capabilities are only as good as those of the experts whose knowledge it contains), and allowing the user to examine the approach that the system followed in obtaining a solution will frequently indicate what other steps might be introduced in the system to improve its performance.

This in itself is an important feature of a knowledge-based system. The structure is such that reprogramming is not necessary in order to modify and improve its performance. Most knowledge-based systems are continually expanding both the knowledge base itself and the heuristics in the inference engine in order to refine the performance of the overall system.

The design of the input-output section of a knowledge-based system is critical to its success. The majority of users are not usually experienced in the use of computers and yet are relatively expert in their own field. It is highly desirable that any information that must be supplied by the user be requested in a form to which the user can relate, and the output must similarly be provided in the specialized language of the user. Up to this time, a conventional computer keyboard has been the most common input mechanism for data that the user must supply; with the advent of techniques such as the touch screen and the "mouse," it is probable that in future systems most input requirements will be handled without requiring any typing skills on the part of the user.

APPLYING A KNOWLEDGE-BASED SYSTEM TO BUS MAINTENANCE

A knowledge-based system for bus maintenance will differ somewhat from other systems in that both the knowledge and the heuristics will be derived from the composite expertise of a number of sources. In the initial stages of development of a knowledge-based system, however, it is usual to concentrate on one subsystem that can be used in the development of a prototype. After the potential of the system has been shown through application of the prototype to real-world problems, the knowledge base can be extended to cover the balance of the system. At least in the early stages, therefore, it will probably be possible to develop an effective prototype based on the experience of one or two experts working on one particular subsystem--preferably one that is generally considered to present significant difficulty in the attempt to diagnose the cause of specific failures.

The development of a prototype system should concentrate on the diagnosis of difficult faults. Examples would be those that take a considerable amount of time to diagnose under normal conditions or cases where a fault is reported frequently and repetitively, even though the correct repair action is supposed to have been taken.

Development of a knowledge-based system is an interactive process between the software developer (or knowledge engineer) and the expert. Initially an attempt is made to determine the logical processes that the expert follows when he makes a diagnosis and the information that he requires. Frequently diagnosis is made through a process of elimination, and this must be included in the heuristic. This is a most important feature, because much of the power of a knowledge-based system is the ability to prune the large number of possibilities that exist into a small and well-defined set that can then be investigated in more detail. Frequently it is not possible to come up with a unique solution, and it is then necessary to develop a weighting procedure that will allow the alternatives to be presented in order of probability. At all times the procedure that led to a decision must be available, so that the expert can review the process to confirm that it reflects his normal diagnostic process.

After an initial set of heuristics has been established, it must be refined by practical application in a real-world situation. When a correct diagnosis has been obtained, the procedure can be annotated to show that, for the given set of conditions, the procedure was correct. Where an incorrect diagnosis occurred, or the knowledge-based system was unable to reach a conclusion, the decision process must be analyzed and additional heuristic rules of thumb or data introduced to provide the correct solution. Finally, after an acceptable level of accuracy has been achieved, the system can be put into general use. Even then the refinement process continues, because cases of incorrect diagnosis will continue to occur, and the expert must again be consulted to improve the system.

As an indication of the accuracy that can be achieved, a diagnostic system for pulmonary diseases has achieved an accuracy in initial diagnosis of approximately 80 percent (9). Although this might not appear high, it is slightly better than the accuracy of a specialist in the disease and almost 20 percent higher in accuracy of initial diagnosis than that of a general practitioner.

Fortunately, the high degree of commonality in the subsystems that are in common use in the transit industry (even with buses from different manufacturers) would make a knowledge-based system generally applicable. Also, in contrast to most other computer-based systems, the value of a knowledge-based system would probably increase as the size of the transit system decreased, because the smaller transit systems are less likely to have the in-house experts that are available at larger agencies. For this reason, it may be desirable to incorporate diagnosis of less obscure problems in a system so that it would be of more use to small transit agencies.

Although modern computer systems are both smaller and less sensitive to their environment than their predecessors, they are still generally not ideally suited to an industrial or workshop environment. (Computers capable of working under adverse environmental conditions are generally available, but usually at a considerably higher price.) This does not appear to be too much of a problem for most transit applications, because it is likely that any computer system would be installed in a relatively benign environment such as a supervisor's office rather than on the shop floor. Alternatively, the computer itself could be installed in a separate room, with ruggedized terminals available for use by the maintenance personnel.

Experience in other applications has shown that although there may be some initial resistance to such a system, the benefits soon become obvious and the users become the strongest proponents. Probably the only exception is in the medical profession, where fears have been publicly expressed that the introduction of an expert system for diagnosis would make the necessary skills too widely available, adversely affecting the specialists in the field.

USER INTERACTION WITH THE SYSTEM

An expert system normally uses a dialog with the user in order to determine the information on which it can base its decision. In order to minimize the skills required of the user, a multiple-choice menu is provided so that the user is only required to answer yes or no or key in a number. Even this is not required with the most recent installations; the user is only called on to place a cursor over the appropriate answer by using a joystick or a mouse.

With the computer display indicated by () and the response by [], a typical sequence of operations would be as follows:

(What is the bus number?)
[User inputs bus number.]
(You have put in bus number xxxx. Is this correct?)
[User types in "y" for "yes" or "n" for "no." If the answer is no, the computer repeats the first question.]
(What is the mileage?)
[User keys in the mileage.]
(You have entered xxx,xxx miles. Is this correct?)
[User types in "y" for "yes" or "n" for "no." If the answer is no, the computer repeats the question.]
(What is the problem?)

At this point the computer would show a list of the most likely problems, such as:

1. Brakes,
2. Air conditioning,
3. Low power,
4. Starting.

Because it is unlikely that all the possible problems could be displayed on a single list, the final item would be "Display next list." If this was selected, a further list of problems would be displayed.

When the user selected a problem, another list of questions would be asked appropriate to the particular problem selected. It is feasible, in many cases, to answer "don't know." After a certain number of questions had been asked and answered, the computer would provide a message saying:

(Please wait. I am working on the problem.)

It is quite possible that the computer will find that it does not have all the information it needs to make a decision, in which case it would ask for the user to provide it. Eventually, however, a probable solution would be obtained, and the computer would display a message, such as

(Since you say the freon pressure is correct, the most likely cause is a slipping clutch. Do you know how to check that the clutch is working correctly?)

If the user inputs "y," the computer could display:

(If the clutch is operating correctly when you check it, we will have to look for the next most likely cause. When you log on, type "c" to continue this diagnosis.)

It is also possible for the computer to provide additional information that could be helpful. For example, one output could be

(The problem is most likely fuel dilution due to transmission fluid entering the sump through a faulty bearing seal. Bill Smith of XYZ had this problem with the same model of engine and transmission in 1984. You can call him at xxx.yyy.zzz for additional information.)

This is typical of the type of information that a knowledge-based system can hold in its data base to assist the user.

IMPACT OF KNOWLEDGE-BASED SYSTEMS ON TRANSIT BUS MAINTENANCE

Although no knowledge-based system has been developed for transit bus maintenance, General Electric has developed a system, CATS-1, for diagnosing diesel engine malfunctions. It can display locomotive components on a graphics display and demonstrate repair procedures on a video monitor. CATS-1 uses both forward and backward chaining, and is based on a knowledge base of diagnostic rules and facts derived from their top locomotive repair expert (6). Unfortunately, no information on cost or performance is available at this time, and because there are no other systems directly comparable with that required for transit bus maintenance, it is difficult to obtain a quantitative assessment of the impact of such a system on transit maintenance. However, at least two other diagnostic techniques have been used in the transit industry. These are spectrochemical oil analysis (10), used by a number of transit systems, and the Automated Bus Diagnostic System that has been demonstrated by the New York City Transit Authority (11). Experience with these techniques provides an indication of the benefits that might be expected from knowledge-based systems.

Spectrochemical oil analysis of engine defects is based on analyzing the chemical properties of a sample of oil drawn from the sump of a diesel engine (or transmission when transmission defects are being analyzed). An expert can, using his experience, predict with a high degree of accuracy the probability and type of failures that are likely to occur on the basis of the trace chemicals that are detected in the analysis. This allows the appropriate corrective action to be taken before a catastrophic failure, leading to a breakdown, occurs. One of the earliest studies on the application of spectrochemical oil analysis to the transit industry clearly showed the benefits of such a system (10).

Spectrochemical oil analysis was started as a normal preventive maintenance procedure at the Autoridad Metropolitana de Autobuses (AMA) in San Juan, Puerto Rico, in December 1970. Each coach was scheduled for a minimum of one sample per month. Figures 2 and 3 show the trends in the analyses of the oil. A "red" report indicates a critical abnormality; a "white" report, no abnormality. It can be seen that the number of buses that showed critical abnormalities initially increased and then subsequently fell, whereas the number of buses with no abnormalities steadily increased. Although there is no direct evidence that shows a correlation between the improved diagnosis of potential failure conditions and a reduction in road calls (unfortunately, road call data for this period were unavailable), the reduction in the number of buses with critical abnormalities and the increase in buses with no abnormalities suggests that an improvement in the reliability of operation also occurred.

The Automated Bus Diagnostic System, demonstrated in New York in 1982, is even more closely related to a knowledge-based system in that the data obtained from an instrumented bus are analyzed to diagnose the cause of problems that have been detected in an earlier check performed at the service island. The diagnosis is purely automatic, but is based upon that of experts in bus maintenance (11).

Unfortunately, deficiencies in the data collection process make it difficult to draw conclusions that would be considered statistically valid. Nevertheless, some general conclusions can be made based on

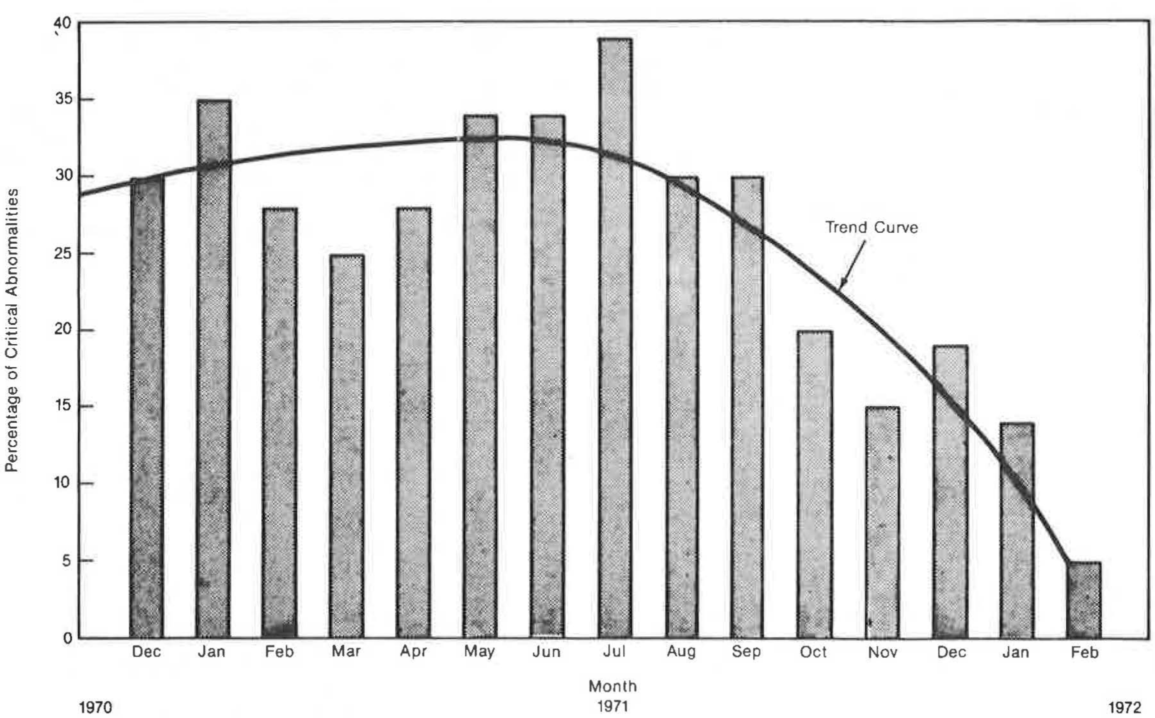

FIGURE 2 Summary of red reports for AMA.

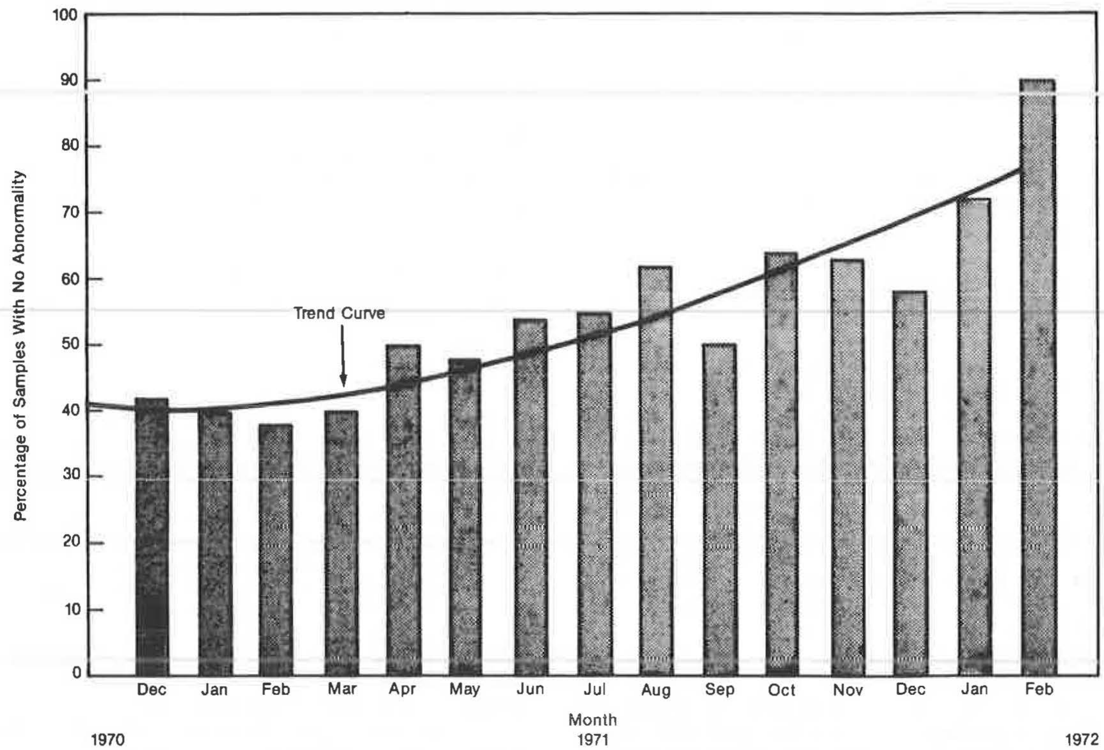

FIGURE 3 Summary of white reports for AMA.

the data that were collected. First, as expected, there were fewer road calls for the buses that were being evaluated on a daily basis by the automated diagnostic equipment than for the control group that were receiving the normal manual inspection and repair (Table 2). Second, the buses in the test group were out of service for more days for repair than the control group. This suggests that defects were being detected by the diagnostic equipment and repaired, which led to the lower number of road calls. Significantly, though, at the end of the 6-month test period the test group had fewer days out of service for repair than the control group, which suggests that all the incipient failures had been detected.

TABLE 2 Number of Road Calls and Out-of-Service Days

Date	Number of Road Calls: Test Group	Number of Road Calls: Control Group	Out-of-Service Days: Test Group	Out-of-Service Days: Control Group
February 1982 (part)	8	11	86	14
March	6	18	250	42
April	16	21	181	74
May	15	22	84	86
June	12	33	86	134
July	21	16	51	157
Total	78	121	738	507

No measurement was made of the time necessary to diagnose a fault with the automated equipment versus that with conventional expertise. However, individuals were asked to estimate the time that an expert would take to diagnose a fault. This was compared with the time taken using the automated diagnostic equipment. In every case there was a significant time saving. On the basis of the experience in New York, an improved version of the Automated Bus Diagnostic System will be tested at four other transit systems, including Flint, Michigan; Syracuse, New York; and Nashville, Tennessee (12).

It can be seen that there is a strong indication that the introduction of a knowledge-based system would benefit transit bus maintenance, both in terms of fewer road calls and shorter times for diagnosis. Without more directly related experience, however, it is not possible to determine whether the reduction in costs of road calls and diagnosis would offset the additional repair costs that would apparently result, and also whether the costs of operating and maintaining the system could be offset by savings in the overall maintenance operation. Because of the potential benefits, however, there is good reason to develop and test a prototype system so that both maintenance cost savings and improvement in the quality of performance can be determined as well as the costs of operation and maintenance.

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Information Systems in Bus Fleet Management

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ABSTRACT

The rate of use of computerized fleet management information systems in the transit industry is investigated, and it is concluded that transit fleet management underutilizes automated systems. Next the evolution of the state of the art of fleet management systems is examined. Directions are hypothesized for the future development of computerized systems. Last, elements that should be considered in the planning of a system are discussed.

Computerized management information systems were first introduced to industry in the late 1950s (1), typically for accounting and other applications-oriented activities (such as inventory tracking and labor and payroll reports). By the mid-1960s many industries recognized the need for and value of information in a broader sense. At that time computer technology had evolved to the point where large, integrated systems were feasible. Since then, information systems have had more than 20 years to develop and they have permeated most aspects of business and government.

One would expect that bus fleet management would be no different than similar areas of industry and that record keeping and information preparation would be largely computerized by now. As an indication of the rate of computerization of bus fleet information in the transit industry, Kliem and Goeddel summarized the results of a 1980 American Public Transit Association (APTA) survey of computer applications at transit agencies (2,3). They found that "of the 54 transit properties identified (representing approximately 65 percent of the total industry's vehicle fleet), 28 reported the use of automated information systems for vehicle fleet maintenance." Slightly more than half does not indicate an overwhelming rate of computerization, but by 1984, certainly more have become computerized. Even the 1980 rate (52 percent of those surveyed) suggests that computers have a strong foothold in bus fleet management.

After a closer look at the list of systems claiming computerized maintenance information systems, one with which the authors were familiar was spotted that appeared odd. This transit system was a department of the city's government. A clerk on the bus maintenance staff retyped the information from work orders into text files on the city's mainframe computer. The text files were used to produce paper copies of work histories, but they were never machine processed for summary information. Therefore, the computer was acting largely like an electronic file cabinet. Further, because the records were not machine analyzed, there was no need to be totally accurate in data entry and repair cases were often lost. Technically this system kept maintenance records by using a computer, but this could hardly be termed an information system. Unfortunately, the APTA survey used by Kliem and Goeddel is insensitive to the degree of computerization of record keeping. Therefore, the rate of computerization in fleet management is probably better measured by whether the system uses computers as well as the degree of sophistication of the use of computerized systems.

A better indication of the rate of computerization is given in the results of a 1983 survey (more than

3 years after the APTA survey) conducted by the General Accounting Office (GAO) (4). GAO sent surveys to 205 transit systems that received UMTA funds.

GAO's data were later independently analyzed by Cook et al. (5). They found that about 60 and 40 percent of the systems surveyed used computers in some fashion to keep maintenance cost and maintenance frequency records, respectively. This rate of use of computers in keeping maintenance records approximately agrees with the findings of Kliem and Goeddel. However, the proportion of transit agencies that have information systems (sophisticated systems) that allow the total use of computers for keeping and summarizing operations and maintenance cost records and maintenance frequency information is only 4.3 and 3.2 percent, respectively.

In the strictest sense, an information system is not simply a system used to keep records. Mathews defines the difference between a record-keeping system and an information system by defining information (1):

> Information is that part of the data which can be used to increase knowledge of that which is unexpected. Conversely, if a message is completely predictable no information is gained by receiving it.

If Mathews' definition is used, data stored directly from records is not information. Therefore, data storage systems are not information systems. Further, computer systems that store maintenance records but cannot analyze the data to derive new information (like failure frequencies) are not information systems. By using the results of the GAO survey and a rigid definition of information, it can be concluded that at most 4.3 percent of transit systems (in 1983) really had fleet management information systems.

On the basis of the assumption made here to define information systems, the transit industry has a very low use rate of computerized information systems. Currently there is pressure across the transit industry to hold down operating cost. Much of the cost-cutting pressure is the result of the federal government's interest in cutting operating subsidies (6). Because, on the average, maintenance costs account for almost one-fourth of total transit operating cost, maintenance is a conspicuous target for cost control and reduction (7). However, as Kliem and Goeddel point out, "the costs of transit maintenance have perplexed many transit operators because of the lack of supporting data" (2). Supporting detailed information is available through integrated computerized information systems. This information will provide a better understanding of the relationship of maintenance activities to cost and should result in better management and control of costs.

In related industries, a better understanding of the relationship of maintenance activities to cost through computerized information systems has allowed managers to achieve great savings. For example, Becker and Hayden note that in truck fleets, maintenance cost savings that range from 15 up to 45 percent are possible when better management practice can be instituted (8). They go on to comment, "A well-designed management information system is a vital adjunct to successful implementation of management control."

Because of the ability to better understand the factors related to maintenance cost and therefore better manage maintenance through computerizing information systems, the industrywide pressure to cut costs, and the low rate of computerization, there should be a great deal of impetus for fleet managers to use computerized information systems. Further, there are two forces at work that make this an advantageous time to increase the use of computerized information systems:

1. The prices of hardware and software packages have dropped dramatically. For example, microcomputer-based maintenance information systems (hardware-software packages) that have the capability to handle small systems (less than 100 buses) can be purchased for only $10,000 to $20,000 (9).
2. The capabilities of software packages have been dramatically improved. Software being developed now has reduced the computer programming know-how required to create even complicated systems. For example, some have even used off-the-shelf data base management systems (DBMS) and inexpensive microcomputers (less than $10,000) to create their own customized information systems (10,11).

Reductions in prices of management information system packages and increased capability and flexibility of software have made computerization more attractive and has also made it easier for vendors and consultants to enter into the information system sales market. Although a great deal of competition from suppliers is healthy, for the consumer it may create a great deal of confusion.

Besides the confusion created by variety in the marketplace, transit agencies are not generally well skilled to deal with computerization. As an indication of the need for training of transit staff in computer use and computer applications, a recent TRB workshop (which was attended predominantly by transit system staff) recommended the development of "training programs that would aid in the transition from manual to computerized maintenance information systems" (12).

The lack of experience with computing systems in the transit industry and the variety of available computerized information systems doubly confound the overall process of procuring bus fleet management information systems. Therefore, the purpose of this paper is to arm potential consumers with insights into bus fleet management information systems. Specifically, the rather broad topic of the functional evolution of information systems is examined and the paper concludes with the rather narrow topic of what one should consider while planning for a bus fleet management information system.

THE EVOLUTION OF BUS FLEET MANAGEMENT INFORMATION SYSTEMS

The first computer-based management information systems were batch processed. Typically, the maintenance manager sent coding sheets containing monthly records to a central computing facility where the data were processed. Processed information was then sent back to the maintenance manager.

This simplistic situation is represented by the flow diagram in Figure 1. The data are entered into the system and tabulated to generate information, which is output in a standard report format. There is no interaction between the manager and the system.

Today, bus fleet information systems have largely evolved to the point where the user can interact with the information system. Interaction may be through the selection of report formats, statistics reported, tolerances for the automatic flagging of problem vehicles, and so on. The interaction between the user and the system is shown in Figure 2. The user inputs data into the system and the system produces information that is output in standard reports. The user then interprets the information and can query the system to process the information differently.

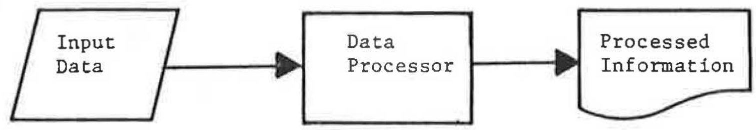

FIGURE 1 Evolution of information systems: first-generation system.

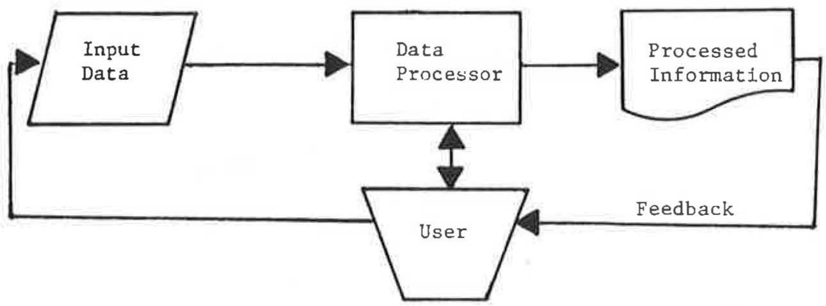

FIGURE 2 Evolution of information systems: second-generation system.

The next step in the evolution of information systems is to add capabilities to perform data analysis and to store past performance. These capabilities allow forecasting, which will project future trends assuming that maintenance policies remain constant. These forecasts can then be used in planning and scheduling. The interaction of the user with the system and the storage system of past performance is shown in Figure 3.

However, bus fleet management information systems do not appear to have evolved to this point. In Anagnostopoulos' recent review of popular bus fleet information systems, he found that none of the nine systems reviewed incorporated maintenance planning, failure analysis, and activity forecasting capabilities (13). This is unfortunate because, as Couture and Paules point out, "These high-level uses of maintenance data are where the most substantial payoffs can accrue to an organization since the information supports decisions affecting performance and cost of the operation months and years into the future" (11).

Forecasting seems like a reasonable next step. However, failure analysis in an operational environment is not a simple task, for technical reasons explained elsewhere (14). Information systems that produce high-quality forecasts are complex. However, maintenance information systems applied in other industries have overcome the complexity of forecasting. For example, in a 1967 article Vlahos points out that even in the mid-1960s, large manufacturers were using maintenance information systems to conduct component maintenance forecasting, labor forecasting, and material needs forecasting (15). Therefore, with greater expenditures on the development of forecasting techniques and the current availability of inexpensive computing equipment, it appears likely that the complexities of transit maintenance forecasts can be overcome and the use of such tools will be feasible for even small systems.

The next step in the evolution of maintenance information systems will include simulation capabilities and mathematical programming models. The simulation capabilities will allow the forecasting of events due to changes in management policy and maintenance practice. Mathematical programming models will be used to select optimal management actions based on simulated fleet maintenance status. The flow of this fourth-generation information system is shown in Figure 4.

In summary, Figures 1-4 show the four generations of management information systems. The current state of the art of bus maintenance management information systems is roughly in the second generation and there are activities underway to help boost the

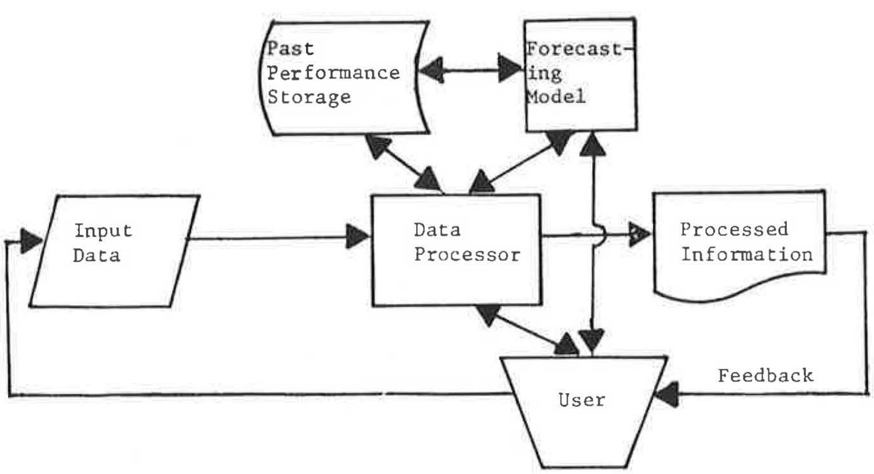

FIGURE 3 Evolution of information systems: third-generation system.

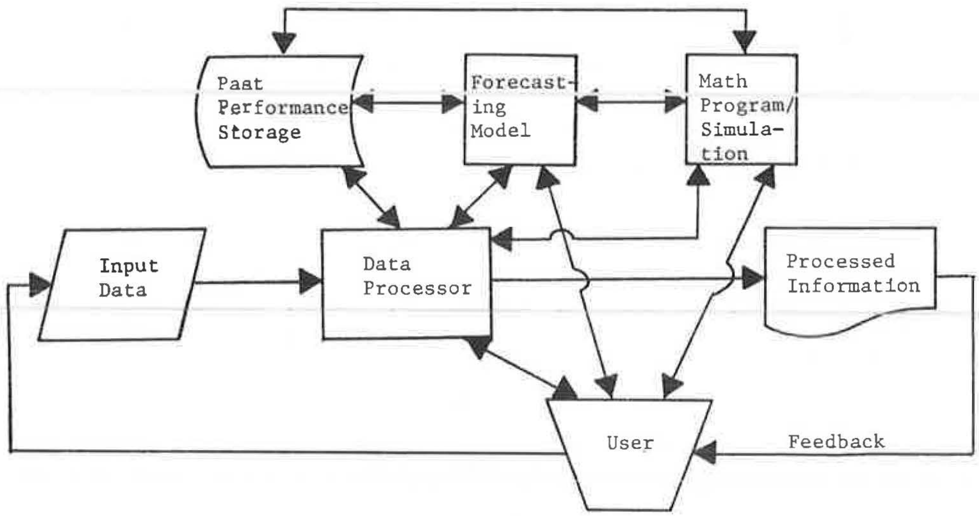

FIGURE 4 Evolution of information systems: fourth-generation system.

state of the art into the third generation (16,17). However, because of the complexity involved, it will probably be several years before quality third-generation systems are available to bus maintenance managers. Therefore, current potential purchasers of systems will have to select a second-generation system. In the next section elements that should be considered during system planning and the attributes of good second-generation maintenance information systems are discussed.

Mathews points out that ideally a maintenance information system is developed in five logical steps (1). They are as follows:

1. Synthesis: The high-level brainstorming takes place and objectives are set.
2. Planning: The information needs and evaluation methods are determined. Planning should result in a system performance specification.
3. Design: The specific equipment, procedures, and training are determined.
4. Implementation: New data collection systems are introduced, and training and system burn-in take place.
5. Maintenance: During its useful life the system will require maintenance, modification, and improvements.

Whether the system is developed in house, purchased as a package, or to some extent both, it should go through all five steps. This following discussion focuses on step 2 (planning), and it is suggested that readers contemplating the implementation of a system go on to read more in-depth literature (1,18,19).

MAINTENANCE AND INVENTORY SYSTEMS PLANNING

Planning is emphasized in this paper because it is the most unique of the five steps to the specific system created. Planning sets the performance specification that should be followed in system design, implementation, and maintenance (steps 3, 4, and 5). The generation of system objectives (step 1), although important, is at a more subjective level, whereas the development of the system plan deals concretely with the essence of the system's creation.

The discussion of planning is divided into four subsections. At the primary level of planning, there are a nontechnical understanding of information flows and the decision as to what the maintenance management's information needs are. Next are planning considerations for maintenance and inventory systems. Although each system is covered in a separate subsection, in operation the link between the two modules of a bus fleet management information system should be clear to the user. Planning considerations of the man-machine interface are discussed last.

Starting Fleet Maintenance Information System Planning

The most important aspect to consider in planning is the organizational objectives in directing the flow of information. All too often, the paths along which information should flow are obscured by physical and functional limitations. For example, the cost of parts and components withdrawn from the inventory is needed for accounting purposes. To the accounting department the identity of the individual bus on which the components were used may be unimportant. However, component use, component cost, component identity, vehicle identity, and so on, are all important to the fleet manager. Therefore, either the fleet manager keeps redundant records or his information needs are neglected because of differences in functional goals of groups within the organization.

To overcome the difficulty in finding the logical flow of information, it is necessary to conceptually "peel back" physical and functional barriers. To understand where information should flow, the planner must examine the decisions that have to be made at each step of the organization's hierarchy. For example, the shop supervisor should have access to time standards and tolerances for given activities so that this information can be used in the scheduling of activities on the shop floor. However, it would be inappropriate to give the same time information to a mechanic being assigned a work order.

The sequence of decisions is the primary channel along which information should naturally and necessarily flow to achieve the objective of the organization. Finding this flow is a matter of locating the points where decisions are made. Detailing the type of information needed at each decision point is a matter of breaking down the information needs for the decisions made at that point in the organizational hierarchy.

A structured analysis of information flows and decision points is not as difficult as it sounds. A common approach to this type of analysis involves drawing a data flow diagram of some type. The analysis starts by pictorially representing existing information flows with a diagram of links (data flows) and nodes (processes, data records, and external entities). The jargon of computer techniques is not involved in diagramming data flows, and nontechnical personnel participate in the system planning process [a bus maintenance example has been provided by Maze and Cook (16), and general instruction on data flow diagramming may be found in another publication (20)].

Diagrams are used because they permit dealing with planning on an abstract, macroscopic level. It is abstract in that the planning is uninhibited by physical or functional constraints of the organization or of computer hardware and macroscopic in that it deals with information flows at the most fundamental level of detail. Thus, once planning has been stripped of detail and physical and function constraints, managers may express their preferences and make trade-offs in selecting

1. What existing information flows should be automated,
2. What new information should be available for decision making, and
3. What new data flows are desirable given that the resource constraints of compiling paper records no longer exist.

Data flow analysis should be conducted even before a computer system designer or system vendor is contacted. This is because the computer system should work within the hierarchy of the existing management system. Of course, this assumes that the existing structure is an efficient one. The outside computer analyst or vendor typically will have an existing package to sell or have a system in mind and attempt to force the existing management structure to fit into the structure of his system.

A computer system helps management to make decisions. It should provide the user with better information but it should not force decision making into a preset pattern. For example, in a recent interview the maintenance manager of a transit system that is known for good maintenance was asked why he did not have a computerized maintenance information system; his answer was that he had not found a computer system that fit his philosophy of management. He wanted a system that would perform existing functions of his paper information system but with greater speed and data intensity and permit the examination of more varied information. This type of computer system would conform to his organizational structure and not the reverse.

Maintenance System Planning

Regardless of the structure of the organization, at a minimum the maintenance system should include information on the following three areas of fleet status:

1. Vehicle reliability: Kapur and Lamberson define reliability as "the probability that, when operating under stated environmental conditions, the system will perform its intended function adequately for a specified interval of time" (21). Because of the complexity involved in failure analysis in an operational setting, measurements of reliability of the type defined by Kapur and Lamberson probably will not be available with current common maintenance packages. However, in a less strict sense, the average miles between road calls and the average miles between component failures can be used as indicators of vehicle reliability.
2. Vehicle maintainability: Kapur and Lamberson define maintainability as "the probability that a failed system can be made operable in a specific interval of downtime" (21). A measurement of maintainability in the sense that Kaper and Lamberson define it is beyond the capabilities of currently available systems. However, in a less strict sense, direct labor hours devoted to various types of repairs per component failure by vehicle type and fleet can be used as an indicator of vehicle maintainability.
3. Vehicle availability: Kapur and Lamberson define availability as "the probability that any system is operating satisfactorily at any point in time and considers only operating time and downtime, thus, excluding idletime" (21). Again, existing systems are not capable of measuring availability in the strict sense. However, information systems should provide such indicators of vehicle availability as the number of open work orders, the average duration of open work orders, current spare levels, and so forth.

Vehicle reliability, maintainability, and availability are rudimentary measures of fleet and vehicle status. As failure analysis techniques mature and become available in information systems, the manager will be able to forecast how these three measures will change with vehicle age and with changes in related activities (e.g., size of labor force, facility availability, and fleet size). Some of the system functional requirements that should be considered during the planning stages are discussed in the following paragraphs.

Comparative Analysis

The information system should be able to produce statistical summaries of maintenance activities in numerical and possibly graphical form. Statistical information aggregated across the entire fleet or across a bus model can be compared with information from individual buses. For example, the comparison of the oil consumption of one bus with the average oil consumption of the other buses of the same model is useful in diagnosing engine problems.

The information system should be able to aid the manager in making comparisons to find buses with exceptional rates (high or low), which indicates a maintenance problem. For common indicators of maintenance problems such as fuel mileage, oil consumption, and brake-shoe life, the system should automatically flag exceptions.

Information Classification

The system should be able to summarize and report information at every level of breakdown imaginable. It should allow the user to analyze any reported activity. For example, the user should be able to identify direct labor costs for brake repairs and stratify the average labor hours at the fleet, model, and individual bus levels. Other classification strata would include the vehicle system or component, the individual or individuals performing the work task, location, and whether the work was preventive or corrective.

Data Storage Structure

The data storage structure should not require the user to input what is routine or obvious. For example, preventive inspections require that certain standard activities take place. It is important that the system capture the occurrence of the inspection, the direct labor time that it consumed, and the identity of the inspector. It is not important to report every activity; the user knows what activities take place during an inspection without the system's help. If a problem is found--for example, suppose that the vehicle needs a brake system overhaul--then the defect and the overhaul should be recorded in the information system. This system of reporting only the unusual is known as reporting by exception.

Another way of minimizing what is stored is to store only an individual description of a significant activity. Other activities can be accounted for in the same general categories. Guidelines for determining whether an activity is significant enough to warrant being described are that the activity

1. Requires more than 1 to 2 hr to complete;
2. Requires the efforts of several individuals;
3. Has a relatively high cost in terms of parts used or labor or both;
4. Is related to vehicle safety systems, because of potential liability;
5. Is one of several included in a standard procedure (like the activities included in a preventive inspection); and
6. Is part of a fleetwide or model-wide campaign.

Hierarchical Scaling of Information

Information must be scaled by the level of detail to match the informational needs of individuals at various levels in the hierarchy of the organization. For example, the general manager may need condensed information in the form of performance indicators. The maintenance manager may only need to see daily summaries of normal activities (e.g., number of preventive inspections conducted and direct labor hours) and exceptions that have been flagged. The shop floor supervisor needs access to daily work logs to make schedules and allocate assignments. The mechanic needs access to work histories to determine whether a diagnosed problem is a recurring one and how it was taken care of previously. Each individual requires access to the same data base but at different levels of detail.

Inventory System Planning

The primary purpose of the inventory system is to help ensure that there are neither too few nor too many parts and components on hand. Too few will increase the downtime of a bus requiring a part or component. Too many will increase the holding costs of the parts and components inventory. To enable the proper management of inventory quantities, the system should automatically flag items below reorder points and produce inventory dollar values and average demand for items. However, in combination with a maintenance system, the inventory system can provide much more assistance than helping to control inventory quantities.

The inventory system should interface directly with the maintenance system. The interface enables the inclusion of part and component costs and use information in maintenance activity information system reports without reentry of data. Part and component use statistics can thus be accessed directly from the maintenance system. Further, the inventory system can flag high-use items. For example, suppose an item like a voltage regulator exhibits an unusually high use rate and is flagged. At that time, the manager can decide whether to investigate this problem further.

To permit the inventory system to interface with the maintenance system, the two must recognize the same coding system. The coding system should include the identity of the bus to which the part was assigned, which allows failure analysis and the tracking of components. Of course, for the interface system to operate properly, all inventoried items must be coded correctly. Not allowing items to be received without the proper code should be one of the error-trapping functions of the system. The coding structure should be simple and recognizable.

The inventory system's primary function is to provide quantity control. However, the information produced by the system should permit the manager to conduct several types of analysis. Three of these are as follows:

1. Vendor responsiveness comparisons: The system should keep track of the time elapsed between issuance of the purchase order for parts and entry of the parts into the system. If a part can be obtained more quickly and with a lower variability in delivery time, fewer parts need to be held in inventory. Therefore, the shorter and more reliable the delivery time, the smaller the reorder quantity. The smaller the reorder quantity, the smaller the inventory, which results in lower holding costs.
2. Vendor parts reliability: The maintenance system's information on frequency of failure can be stratified by vendor identity to make reliability comparisons of parts from different vendors. For example, it would be useful to compare the mean miles and variance of miles between brake-shoe failures. This comparison would determine which vendor provides shoes that last the longest and are consistent in quality. Differences in the physical reliability of parts from different vendors can be traded off with purchase price and vendor responsiveness.
3. Component rebuild versus purchase comparisons: Parts and components can be divided into two types, expendable and repairable. Expendable parts are those that are used only once. Examples of expendable parts include filters, relays, light bulbs, and body parts. Repairable parts are those that may be used many times on different buses; after each use the part is repaired, reconditioned, or overhauled. Examples of repairable parts include engines, transmissions, and starter motors. The management of repairable parts is much more complex than that of expendable parts. In his study of transit agency maintenance activities, Etschmaier found that very few managed repairable parts inventories properly (22).

To be able to manage repairable parts requires that the manager be able to track the part through cycles of refurbishment. Tracking of repairable parts permits comparison of failure frequency and costs of in-house versus off-property repairing of parts. Tracking of individual repairable items also permits the determination of desirable inventory quantities of repairable items.

Planning Man-Machine Interface

The proper planning of the interface between the user and the system is probably the most complex aspect of the system plan. The behavior of the system is highly predictable. However, the behavior of the user is not. At the two ends of the system, data input and information retrieval, the system must interface with the user. At these two points the system must be flexible enough to forgive and adjust to the idiosyncrasies of the user. The problem of creating a well-designed man-machine interface requires a mixture of computer science and psychology.

Data Entry

Given the state of the art of computer equipment, all data entries should be conducted at an on-line terminal. With an on-line terminal system, all data entered should be checked for accuracy while being entered. For example, when a bus mileage is entered from a work-order report, the system should check to be sure that the mileage is greater than that reported in a previous work order for the same bus and that it is not greater than the mileage normally traveled in the time interval since the last report. Any errors found are immediately identified, thus permitting the user to reenter the correct information.

The ease with which the user can interact with the system is termed "user friendliness." There are several ways to increase the friendliness of the data entry process. Some examples are as follows:

1. The data entry screen should be set up to replicate the input source document. A screen with specific areas to enter data is known as a mask. The mask enables data entry personnel to follow the source document without being concerned with the input screen. To understand the importance of this setup, suppose that the source document has the employee number before the vehicle number and the screen has the vehicle number before the employee number. During data entry the user has to transpose the information, which creates the possibility of generating errors.
2. Input validation should be done on a field-by-field basis. This means that all information to be input into a mask does not have to be entered before the system performs the validation process. Because the data are reentered on a field-by-field basis, when an error is flagged the user can choose either to correct the data element in error or to recognize that the data element is in error, enter the rest of the data called for by the mask, and later correct the element in error. Suppose, for example, that a vehicle number for a work order is entered and the number is not found in the master file. When the error in the data element is flagged, the user can check to see whether the vehicle number was entered correctly from the work order. If the number on the work order is in error, the user can finish entering the other data from the work order and later determine the correct number.
3. Error messages that describe the actual error condition should be provided instead of an error code number. When an invalid vehicle number is entered, the error message should state, "invalid vehicle number" or "vehicle number not on master file," not "error 102...; see documentation."

Reporting Information

One of the greatest advantages of a computerized system is that it can process vast quantities of information quickly. However, the production of large quantities of information can also be a detriment. Too much information can bury the valuable information. For example, when interviewed, a fleet manager of a transit system with a computerized information system explained that he did not use the reports because they were too confusing. The default reports provide too much information and too often the data are labeled in non-English, alphanumeric codes.

To be useful, reports must be selective in providing only the information that the manager needs, and the system should provide English labels. Some characteristics that reports should have to increase their usefulness and to increase the efficiency of the manager in interpreting them are as follows:

1. Uniformity: Reports should have uniform formats so that the user can recognize their scope and purpose.
2. Information presentation: Reports should be designed for maximum visual impact and readability. Graphical presentation of material is more easily interpreted. Thus, if possible, statistical data should be accompanied by computer-graphic plots.
3. Report accessibility: Terminals, printers, and report paper copies should all be accessible to the manager.

The report generator of the system should have the ability to process several reports in a uniform format. These reports should be varied in detail in accordance with the level of the user in the hierarchy of the organization. For example, the fleet manager should have a series of summary reports. Typical examples of management-level summary reports are as follows:

1. Maintenance cost by vehicle system (e.g., air conditioning, engines, chassis) report enables the manager to identify high-cost (in labor and parts) systems within the fleet;
2. Vehicle class performance report provides average operations and maintenance cost information by vehicle class; and
3. In-stock valuation report provides the manager with current inventory levels and their value.

A more detailed report should be accessed by shop supervisors or when the manager is conducting more in-depth analysis. Typical examples of detailed reports are the following:

1. Bus case history report provides mileage, date, employee, labor and parts cost, and other specific information on each maintenance activity for any specific bus;
2. Component activity report provides detailed information on the maintenance activities on a specific component on every bus or every bus within a class; and
3. Reorder report identifies all stock items that are at or below the minimum established stock level.

CONCLUSIONS

Fleet management in the transit industry is largely insufficiently computerized. Because of the ability to better manage maintenance through the automation of fleet information systems, there should be a great deal of impetus for fleet managers to purchase or build information systems. For those that are currently considering a fleet management information system, this paper provides a brief overview of the state of the art and of considerations in the planning of a fleet management system.

Fleet management information systems currently available to the transit industry are at the second of four stages of the evolution, as outlined earlier. As they evolve, information systems will first develop forecasting capabilities for planning and later develop mathematical programming capabilities for decision analysis. However, before there is widespread use of higher-level information systems, two steps must be accomplished, as follows:

1. In the first section of the paper, computer literacy and the understanding of computer systems in the transit industry were discussed. There are strong indications that transit staff are not generally skilled in the use of computerized systems. This lack of understanding brings on a natural distrust of automated systems. Therefore, it will probably take a broad program of education and training to create the impetus for industrywide acceptance of computerized information systems and the use of such systems as decision-making tools.

2. In the second section of the paper, various levels in the evolution of computerized information systems were outlined. To evolve from the current stage of development will require the creation of forecasting and decision-making techniques. Creation of these higher-level capabilities in information systems in an operating environment is complex and can only be overcome with more research and development.

These two steps will help transit fleet management information systems reach a similar level of use and sophistication as those currently enjoyed by other industries. However, it cannot be stressed too strongly that if done correctly, both steps will be complex and difficult to accomplish. As pointed out by Schmitt et al. in their studies of transit industry staff, transit fleet management has been conservative in its use of computer systems (23). Overcoming past neglect of this technology will not be a simple task.

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