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 anels [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.

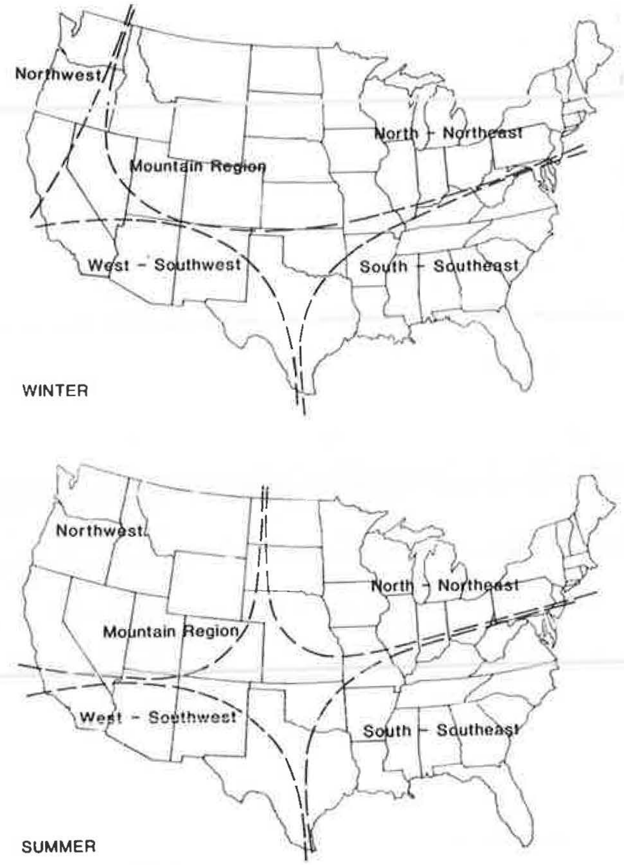

FIGURE 1 Regions with similar climates.

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 ours to determine total regular man hours; and

4. The estimate of regular man hours was compared with the actual figure and all differences were 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[k] assignments in addition to maintaining and servicin[g] transit vehicles. Before the accuracy with which eac[h] agency could account for its manpower could be eval[u]uated, these different work assignments had to b[e] identified and manpower requirements adjusted i[n] order to determine the manpower devoted to the diese[l] 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.

MANPOWER VARIANCES

Taken at a disaggregate level, the manpower requirements for maintaining revenue vehicles varied considerably 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 relationship 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 servicing 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 surveyed there are three primary activities for cleaning and servicing staff: daily servicing, major interior cleaning, and chassis wash. Of the three, daily servicing 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 percent. 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.

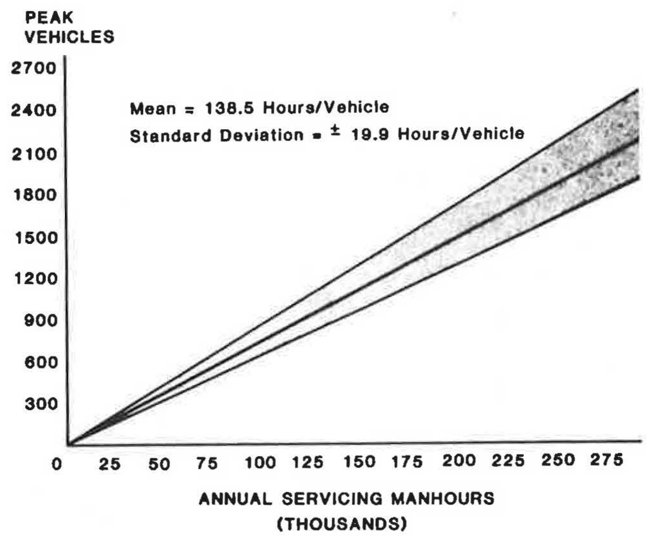

FIGURE 3 Servicing and cleaning man hours.

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 regarding acceptable vehicle appearance (e.g., painting frequency) and campaigns to improve vehicle appearance.

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

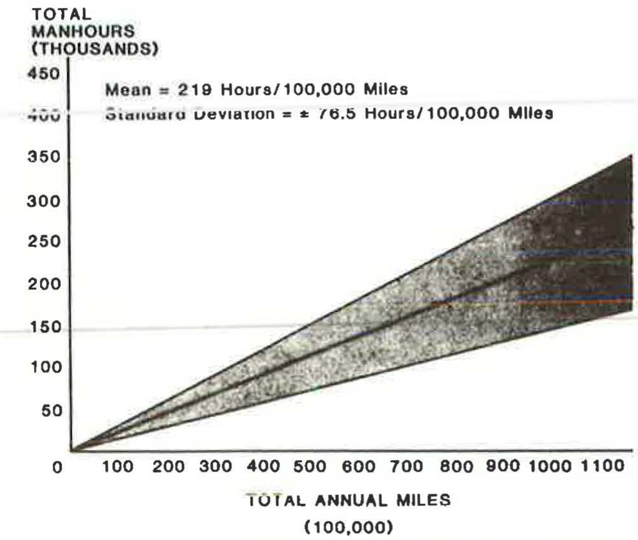

FIGURE 4 Body man hours.

average of 40 accidents per 1,000,000 miles. Man-hour 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 inspection 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,

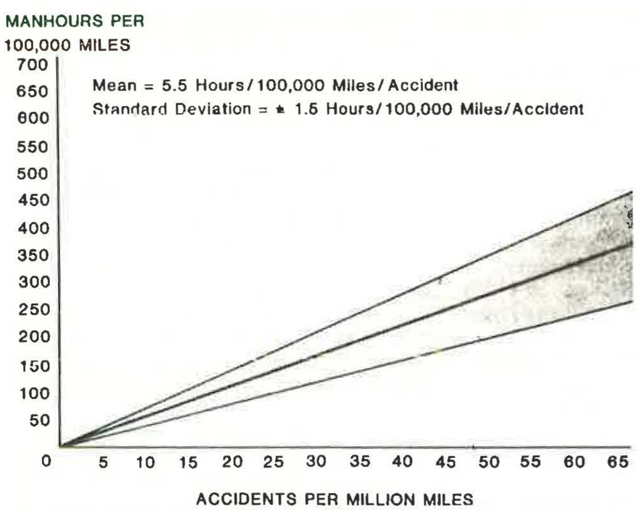

FIGURE 5 Effect of accident rate on body man hours.

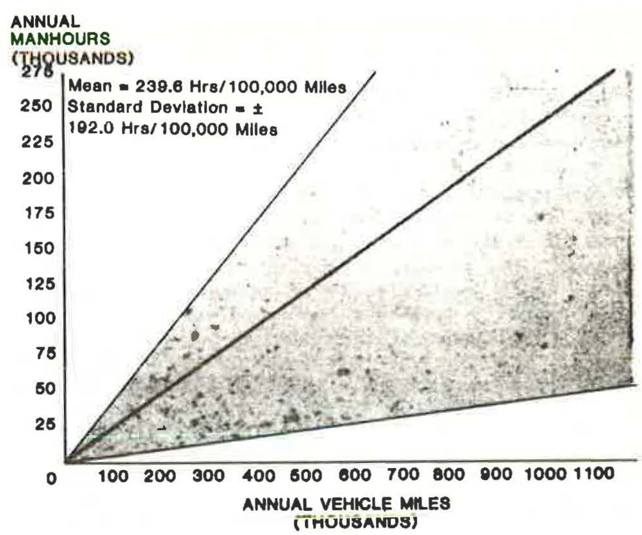

FIGURE 6 Inspection man hours.

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.

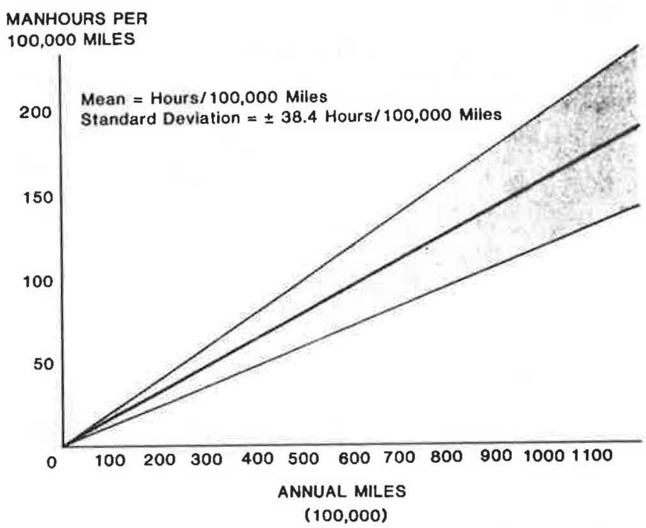

FIGURE 7 Engine and fuel man hours

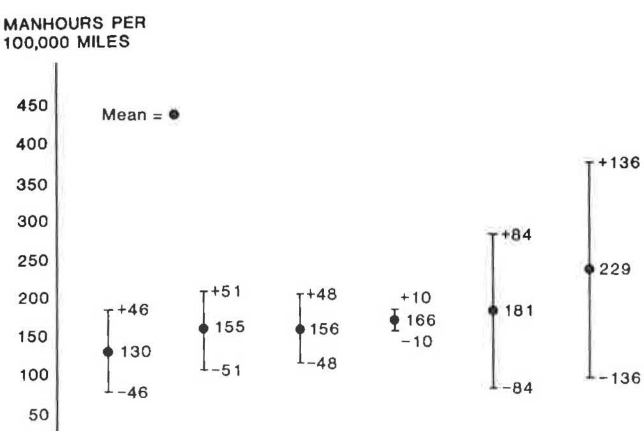

FIGURE 8 Engine and fuel man hours by vehicle type.

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

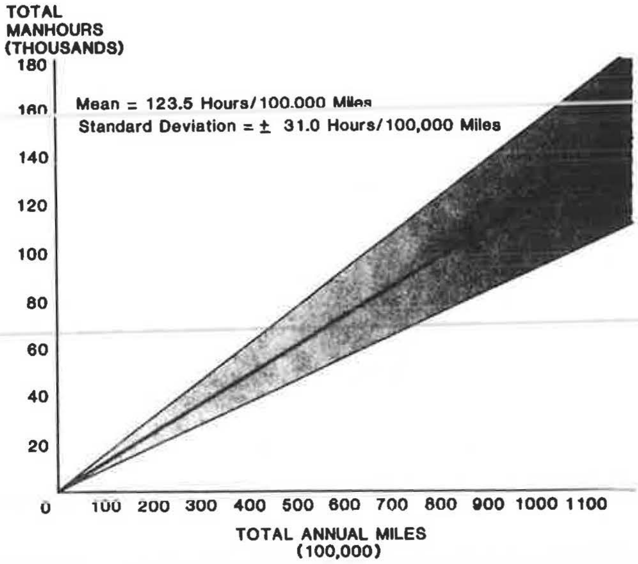

FIGURE 9 Braking man hours.

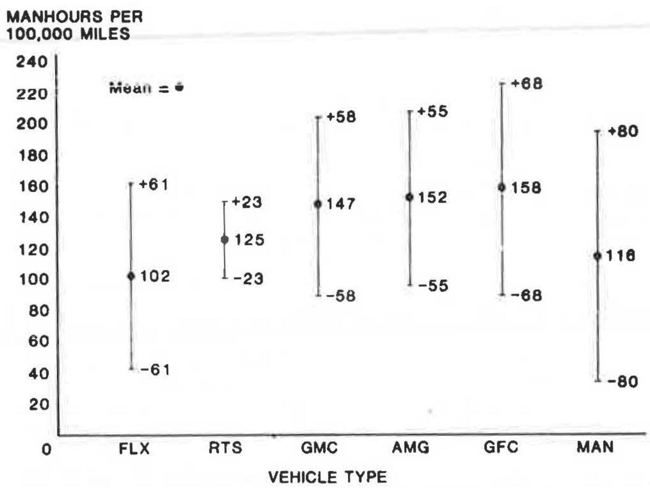

FIGURE 10 Braking man hours by vehicle type.

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-

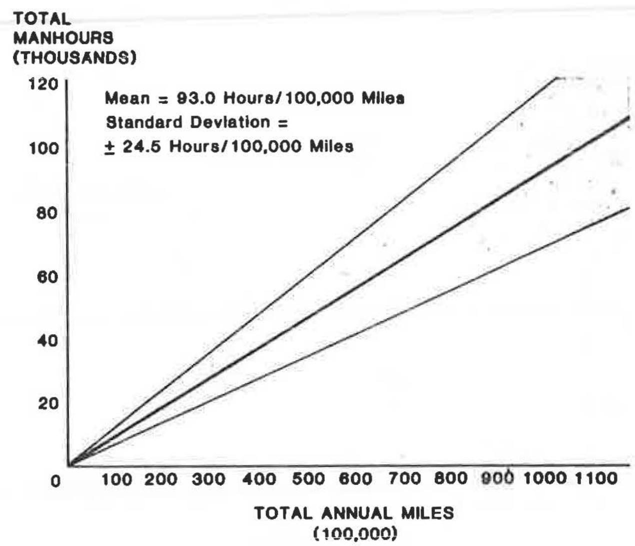

FIGURE 11 Electrical subsystem man hours.

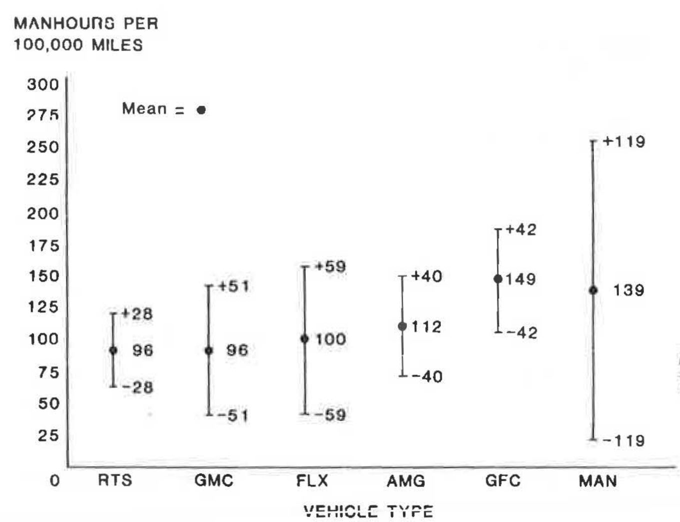

FIGURE 12 Electrical subsystem man hours by vehicle type.

'erent forms. When analyzed independently, the results were misleading because data were not consistent. 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.

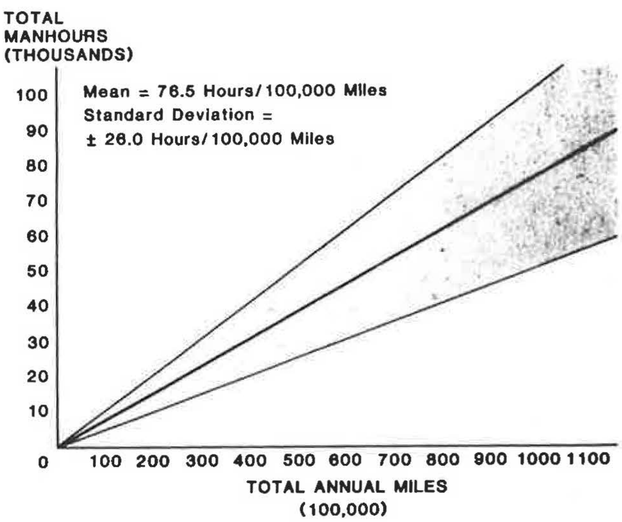

FIGURE 13 Air, steering, and suspension man hours.

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.

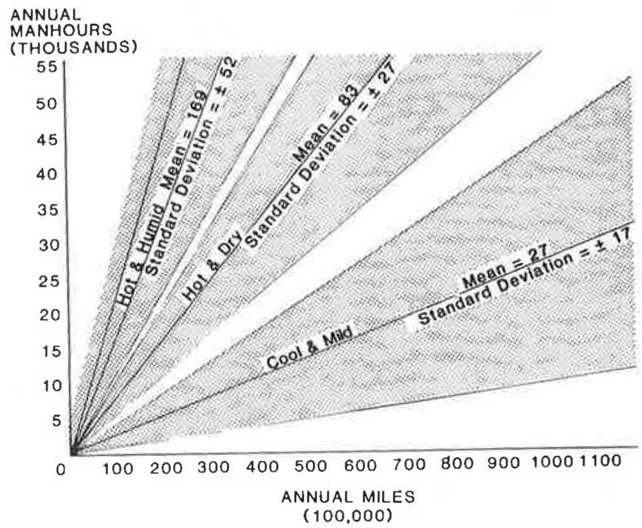

FIGURE 14 Air conditioning, heating, and ventilation man hours.

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

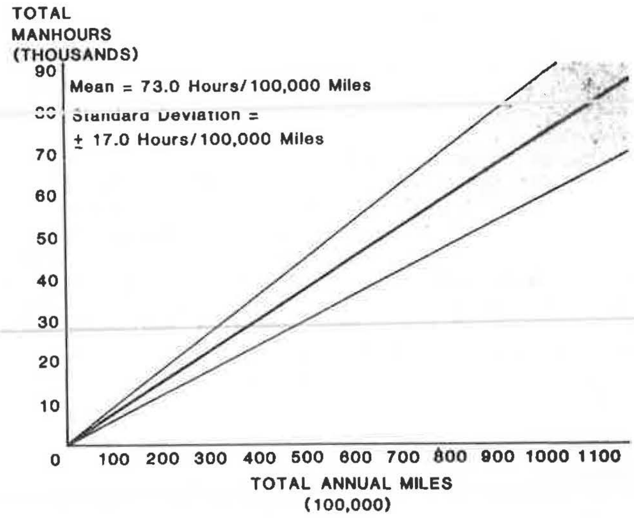

FIGURE 15 Drivetrain man hours.

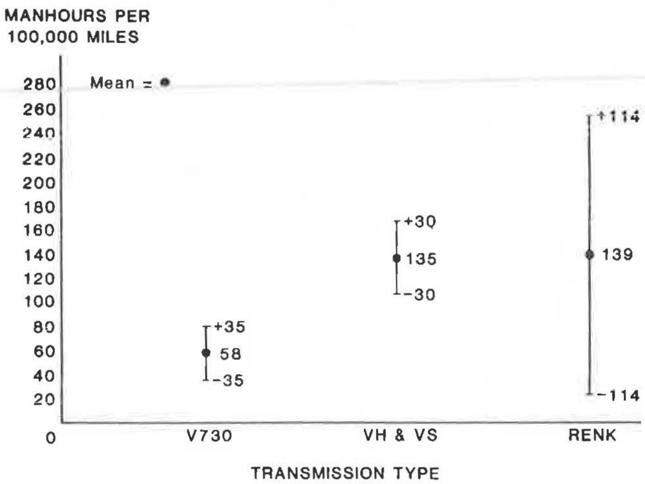

FIGURE 16 Drivetrain man hours by transmission type.

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 desti nation 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.

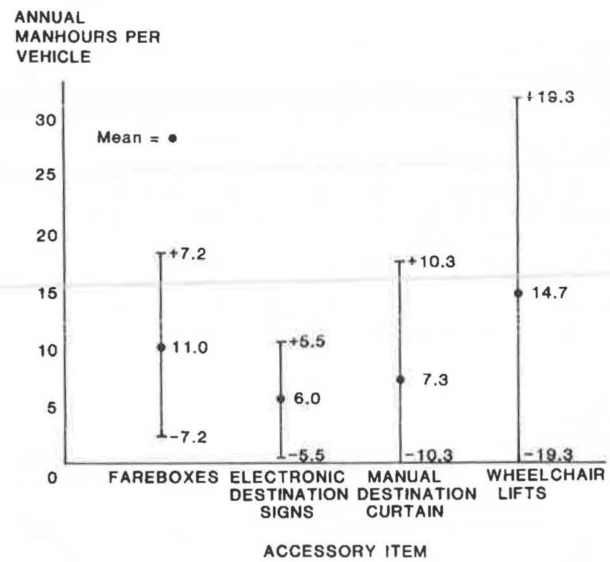

FIGURE 17 Accessory man hours.

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-

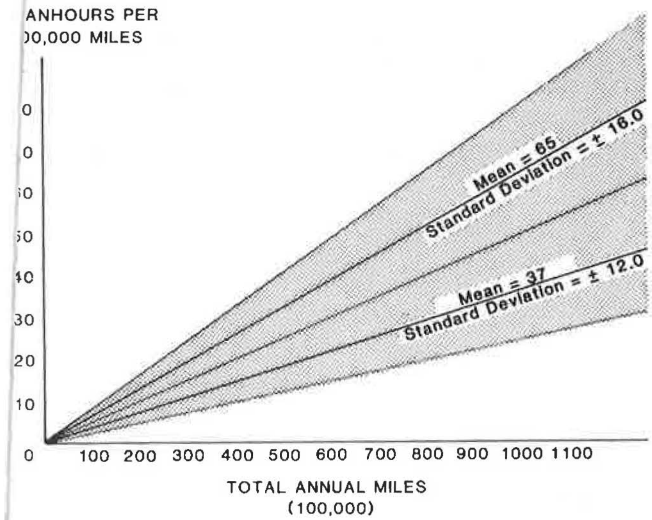

FIGURE 18 Cooling man hours by climate.

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

The research reported here was performed under NCTRP Project 33-3 by Fleet Maintenance Consultants, Inc., with assistance from Booz-Allen and Hamilton, Inc., and was published by NCTRP as Report 10. The authors wish to acknowledge the contributions of the remaining study participants. Subhash R. Mundle, Booz-Allen and Hamilton, Inc., served as coprincipal investigator for the study. James Bodensieck, Fleet Maintenance Consultants, Inc., was responsible for most of the data collection activities. He was assisted in this effort by Donald Schneck, Booz-Allen and Hamilton, Inc. Michael G. Ferreri, Booz-Allen and Hamilton, Inc., provided thoughtful insight that guided the analysis and model development at key points. Douglas Carter managed the data analysis and evaluation activities while associated with Booz-Allen and Hamilton, Inc. A special acknowledgment is extended to R. Ian Kingham, NCTRP, National Research Council. His understanding of analysis techniques and probing questions helped the research team firm up its approach.

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-

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REFERENCE

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

Publication of this paper sponsored by Committee on 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