NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM



# Report 10

# Public Transit Bus Maintenance Manpower Planning

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AREAS OF INTEREST

Administration
Maintenance
Construction and Maintenance Equipment
(Public Transit)

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## NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Administrators, engineers, and many others in the transit industry are faced with a multitude of complex problems that range between local, regional, and national in their prevalence. How they might be solved is open to a variety of approaches; however, it is an established fact that a highly effective approach to problems of widespread commonality is one is which operating agencies join cooperatively to support, both in financial and other participatory respects, systematic research that is well designed, practically oriented, and carried out by highly competent researchers. As problems grow rapidly in number and escalate in complexity, the value of an orderly, high-quality cooperative endeavor likewise escalates.

Recognizing this in light of the many needs of the transit industry at large, the Urban Mass Transportation Administration, U.S. Department of Transportation, got under way in 1980 the National Cooperative Transit Research & Development Program (NCTRP). This is an objective national program that provides a mechanism by which UMTA's principal client groups across the nation can join cooperatively in an attempt to solve near-term public transportation problems through applied research, development, test, and evaluation. The client groups thereby have a channel through which they can directly influence a portion of UMTA's annual activities in transit technology development and deployment. Although present funding of the NCTRP is entirely from UMTA's Section 6 funds, the planning leading to inception of the Program envisioned that UMTA's client groups would join ultimately in providing additional support, thereby enabling the Program to address a large number of problems each year.

The NCTRP operates by means of agreements between UMTA as the sponsor and (1) the National Research Council as the Primary Technical Contractor (PTC) responsible for administrative and technical services and (2) the American Public Transit Association, responsible for operation of a Technical Steering Group (TSG) comprised of representatives of transit operators, local government officials, State DOT officials, and officials from UMTA's Office of Technical Assistance.

Research Programs for the NCTRP are developed annually by the Technical Steering Group, which identifies key problems, ranks them in order of priority, and establishes programs of projects for UMTA approval. Once approved, they are referred to the National Research Council for acceptance and administration through the Transportation Research Board.

Research projects addressing the problems referred from UMTA are defined by panels of experts established by the Board to provide technical guidance and counsel in the problem areas. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out by these agencies under contract to the National Reserch Council, and administration and surveillance of the contract work are the responsibilities of the National Research Council and Board.

The needs for transit research are many, and the National Cooperative Transit Research & Development Program is a mechanism for deriving timely solutions for transportation problems of mutual concern to many responsible groups. In doing so, the Program operates complementary to, rather than as a substitute for or duplicate of, other transit research programs.

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# FOREWORD

*By Staff*
*Transportation*
*Research Board*

This report will be of interest to maintenance managers, manpower analysts, and executive directors responsible for maintenance staff sizing and cost control. Furthermore, it will be of interest to researchers needing information on the variation of manpower experience among bus agencies.

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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 mechanics or maintenance man-hours per miles of operations to perform this function. This approach does not take into account the local operating characteristics and maintenance philosophies which render significant impact on manpower requirements. Further, simple ratios do not address the implications of the influx of a variety of more sophisticated revenue vehicles throughout the transit industry. This research, undertaken as NCTRP Project 33-3, satisfied the need for a more reliable but relatively uncomplicated maintenance manpower planning technique.

The report is structured to provide detailed information concerning the factors causing maintenance manpower needs. The maintenance manpower planning model, produced as a result of this study, quantified the impact of local characteristics such as vehicle-miles, peak vehicles, climate, fleet-mix, accident frequency and, as such, produced an estimate of manpower needs based on the unique characteristics of a particular agency. The model results can be used for both forecasting purposes (i.e., analyzing the impact of a proposed vehicle procurement program) and for comparative evaluation of labor productivity. The model produces a comparison of labor utilization by maintenance function and vehicle type.

The manpower requirements presented in this report are based on experience up to 1983 of 15 representative transit agencies. Caution should be used in reviewing labor differences between bus types (manufacturers). The graphics in the report illustrate what differences exist and not why. Line speed, level of mechanic training, and facility layouts may impact man-hour requirements, but sufficient data were not available to quantify these impacts.

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## ACKNOWLEDGMENTS

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Mr. James Bodensieck, Associate, Fleet Maintenance Consultants, Inc., was responsible for most of the data collection activities. His many years of maintenance experience enabled him to quickly understand the different philosophies of maintenance and obtain the necessary information. He was assisted in this effort by Donald Schneck, Associate, Booz, Allen & Hamilton, Inc.

The data analysis and evaluation activities were conducted under the direction of Mr. Doug Carter, Associate, Booz, Allen & Hamilton, Inc. His dedication to the project was a key element in its success. Mr. Michael G. Ferreri, Senior Vice President, Booz, Allen & Hamilton, Inc., provided thoughtful insight that guided the analysis at key points.

Without the cooperation of the many transit agencies, the project would not have been possible. Staff members from these agencies willingly took time from their busy work days to assist in the project. They are too numerous to name individually but each agency that contributed is acknowledged: Albuquerque Transit System, Ann Arbor Transit Authority, Austin Transit System, Chicago Transit 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, Washington Metropolitan Area Transit Authority.

# PUBLIC TRANSIT BUS MAINTENANCE MANPOWER PLANNING

## SUMMARY

Efficient and economical operation of transit agencies require proper maintenance manpower planning. This crucial element has been based heavily on the past experience of each agency with limited information exchange with other agencies, usually at the request of the funding authority for comparative numbers. Bus operator manpower planning has long been recognized as a necessary function; and, in fact, has been defined and codified in binding labor agreements over the years resulting in sophisticated computerized programs developed to aid transit personnel in establishing operator requirements. However, maintenance manpower planning techniques have been more a function of local practice and have not received equal attention.

In many respects, operator manpower planning is more straightforward than is maintenance staff sizing. Bus operator work requirements are defined by service schedules and labor agreements, and are easily quantified. In most instances, the largest challenge is in defining an efficient extra board to cover operator absences. Maintenance work requirements, conversely, vary from day to day, and measuring an individual mechanic's productivity can be difficult. While some maintenance activities can be scheduled (e.g., revenue vehicle servicing, cleaning, and inspections), many maintenance work functions must be available on demand (e.g., repair). Climate, terrain, fleet mix, and accident frequencies have a negligible impact on operator staffing needs, but they certainly have implications on the maintenance manpower requirements.

In recent years the transit industry has experienced major changes with the introduction of advanced design buses, articulated buses, and buses by new manufacturers. Additionally, new features have been added to make the transit bus more appealing to the riding public. Wheelchair lifts have become a common feature in many bus fleets to make the bus system accessible to the wheelchair bound passenger, and kneeling devices make the transit bus easier to board by the senior citizen by lowering the first step. Electronic destination signs have become increasingly popular. Again, while increasing fleet sophistication has had little impact on the bus operator size, it has had a significant impact on maintenance staff size and training requirements.

Maintenance managers responsible for effective manpower planning have been stymied by a dearth of reliable labor utilization information. Operating in an era of increased vehicle sophistication and decreasing subsidies, maintenance managers cannot afford to rely on simple ratios (e.g., buses per mechanic) to plan for maintenance labor needs. Simplistic reviews do not account for local operating characteristics and fleet compositions. Recognizing the need for an effective, yet relatively uncomplicated, technique for evaluating maintenance manpower requirements and utilization, NCTRP contracted for the present study. The primary objective of the study is to analyze maintenance manpower needs and to develop a model that is sensitive to the local operating conditions of transit agencies of all sizes.

This report is intended for use by maintenance managers, manpower analysts, and executive directors responsible for maintenance staff sizing and cost control. The technique detailed herein is applicable for both forecasting maintenance labor needs and evaluating present labor utilization. In evaluating labor utilization, the technique incorporates local characteristics (i.e., vehicle-miles, peak vehicles, climate, fleet mix, accident frequency, etc.) which allows for an equitable comparison of staffing levels. The developed technique was the result of a rigorous analysis of maintenance manpower needs.

Fifty public transit agencies were contacted to seek their cooperation in providing data on the manpower required to maintain diesel transit buses in today's work environment. Fifteen agencies were selected that represented a cross-section of transit agencies in different parts of the country. An important point in the final selection was the availability of existing detailed manpower information by the different types of buses and at the vehicle system level.

Manpower data were collected during visits to each of the selected agencies. When specific information elements were not available from maintenance reporting systems, interviews were conducted in the shops with supervisors and, in some instances, with mechanics performing actual tasks. Parts clerks were another valuable data source to determine the distribution of rebuilt components in order to calculate frequency of replacement in the various vehicle subfleets.

It was found that maintenance manpower reporting systems for the most part have not yet reached the age of computerization; however, at almost every agency, efforts were underway to overcome this shortcoming. The status of these development efforts varied considerably. A few agencies have operational on-line systems that provide vehicle histories to the working supervisor and mechanic while others are in the beginning stages of system planning to replace existing manual reporting systems. Only a single agency reported to have all maintenance activities on its system.

On the average, agencies were able to account for 81 percent of their total manpower available. Most maintenance managers stated that they believed the time to move buses to and from work positions was not being captured on work orders and was the major contributor to the missing time. The primary cause for maintenance repairs was found to be the number of miles operated by the bus fleets. Eighty two percent of manpower was accounted for by this factor. Other causal factors were investigated. For body repairs, the accident rate at the agency was the other significant factor. Air conditioning/heating/ventilation system repairs were found to be a function of the type of climate. For repairs on electrical, braking, and engine/fuel systems, the type of bus must be taken into account and the type of transmission impacts the amount of manpower devoted to the drivetrain system. The effect of terrain and average speed of revenue service on brake repairs were studied and found to have no measurable impact on manpower requirements.

Service and cleaning activities accounted for an average of 21 percent of all maintenance labor. The daily service and cleaning times varied little between agencies with the differences explained by the relative efficiency of facilities. Time required to move buses within the maintenance/parking facility was greater at those agencies with older, cramped facilities than those agencies with new facilities designed for efficient movement of buses. Agency policy on major interior cleaning frequency and the thoroughness of cleaning procedures also affected the manpower requirements.

Body repairs required an average of 21 percent of total maintenance labor. The number of man-hours was directly related to the number of service miles operated and the agency accident rate. Two agencies with cramped facilities attributed part of their higher reported manpower numbers to on-site body damage.

Preventive maintenance inspection activities, while accounting for 12 percent of manpower on the average, varied significantly across agencies. The manpower required is a function of local policy concerning the frequency and level of inspections. Inspections required by local statutes had a big impact at three agencies with 21 percent of their inspection man-hours devoted to these types of inspections.

Engine/fuel, braking, and electrical repairs accounted for an average of 9, 7, and 6 percent respectively of reported manpower. In addition to miles operated, the type of vehicle was the significant driver of manpower use. Repairs to air systems, air conditioning/heating/ventilation, drive-train and vehicle accessories accounted for an average of 5 percent of maintenance labor for each. Cooling repairs required 3 percent of manpower and repairs to wheels/tires accounted for the remaining one percent.

New types of buses have been placed into service recently at many transit agencies but have not accumulated sufficient miles in revenue service to have demonstrated their maintenance history. Additionally, several types of buses were reported by a single agency; therefore, these were not included.

The maintenance manpower planning model, presented herein, provides managers and analysts with a sensitive, yet relatively uncomplicated tool for evaluating manpower needs. The model is intended to improve transit maintenance performance through better planning, decision-making and control, supported by better labor information availability.

The manpower requirements presented in this report are based on the experience of 15 representative transit agencies as reported to the research team and caution should be used in reviewing subfleet labor differences between bus types. The graphics in the report illustrate what differences exist and not why. Subfleet line speed, level of mechanic training, and facility layouts may impact man-hour requirements, but sufficient data were not available to quantify these impacts.

CHAPTER ONE

# INTRODUCTION AND RESEARCH APPROACH

## PROBLEM STATEMENT AND RESEARCH OBJECTIVES

Proper manpower planning for bus maintenance is crucial to the efficient and economical operation of transit agencies. However, this fundamental element is often determined in a very inexact manner based heavily on past experience and guesswork that may not be appropriate, particularly for transit agencies experiencing major changes in services, equipment, or facilities.

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 mechanics or maintenance man-hours per miles of operation as the primary tools for performing this critical function.

Simple ratios do not adequately reflect the maintenance implications of local operating conditions or fleet composition. Whether comparing one agency's staffing overtime, or conducting a peer evaluation, local conditions and fleet changes make simple comparisons misleading, at best. Transit managers responsible for controlling an effective and efficient revenue vehicle maintenance program are often stymied by a dearth of relevant manpower requirement information. While vehicle-miles, peak vehicles, climate, accident frequencies, speed, terrain, and vehicle type are all believed to contribute to the need for maintenance labor, the quantitative implication of these variables is relatively unknown.

This report focuses on manpower planning techniques for diesel transit bus maintenance only, and it provides transit management better planning tools for maintenance staffing adjustments, data for comparison with representative transit agency data, and assistance in projecting maintenance manpower for optional equipment or subsystems.

The objectives of this study are twofold: (1) to develop a reliable methodology for establishing labor estimates required for maintaining specific bus vehicle subsystems; and (2) to base these estimates on data gathered from several transit agencies, using the methodology. These estimates must account for variance among agencies in such areas as operating environment, labor efficiency, and equipment characteristics, and must be presented in a format that facilitates their use by bus transit agencies for manpower planning and analysis purposes. It is important to note that the maintenance labor relationships detailed herein are not theoretical simulations of potential labor needs, but are actual manpower relationships reflecting actual labor needs uncovered in a rigorous analysis of 15 representative transit agencies.

This report is intended for use by maintenance managers, manpower analysts, and executive managers. In each case, the report is structured to provide detailed information concerning the factors causing maintenance manpower needs. The maintenance manpower planning model, produced as a result of this study, quantifies the impact of primary labor driving variables and as such, produces an estimate of manpower needs based on the unique characteristics of a particular agency. The model results can be used for both forecasting purposes (i.e., analyzing the impact of a proposed vehicle procurement program) and for comparative evaluation of labor productivity. The model produces a detailed comparison of labor utilization (i.e., maintenance function by vehicle subsystem) on an equitable basis (i.e., local operating and fleet mix characteristics are accounted for in the estimate), whereas many peer comparisons do not account for differences in operating characteristics.

## RESEARCH APPROACH

The approach is to develop a manual for use by transit maintenance managers in estimating manpower requirements. It is realistic in that it takes into consideration the vast differences among bus agencies in terms of such factors as fleet size, fleet composition and other characteristics, topography, climate, fleet usage, etc. The approach recognizes that such factors may significantly influence bus maintenance requirements and provides bus maintenance managers with factors for estimating labor time requirements based on their property's site-specific characteristics.

The manual is pragmatic in that it recognizes the limited resources of bus agencies. While establishing maintenance staffing levels can be an extremely complex problem involving many considerations, it is realized that developing a sophisticated computerized manpower planning model may not be in the best interests of the transit community at large. The approach is to develop an uncomplicated, non-automated manpower planning and analysis model that has applicability to all bus agencies regardless of size, but that can be automated easily if so desired.

## AGENCY SELECTION

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

### Selection Methodology

Four criteria were considered in selecting the agencies for the study. They were climatic conditions, fleet size, terrain, and data availability.

<u>Climatic Conditions</u>

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

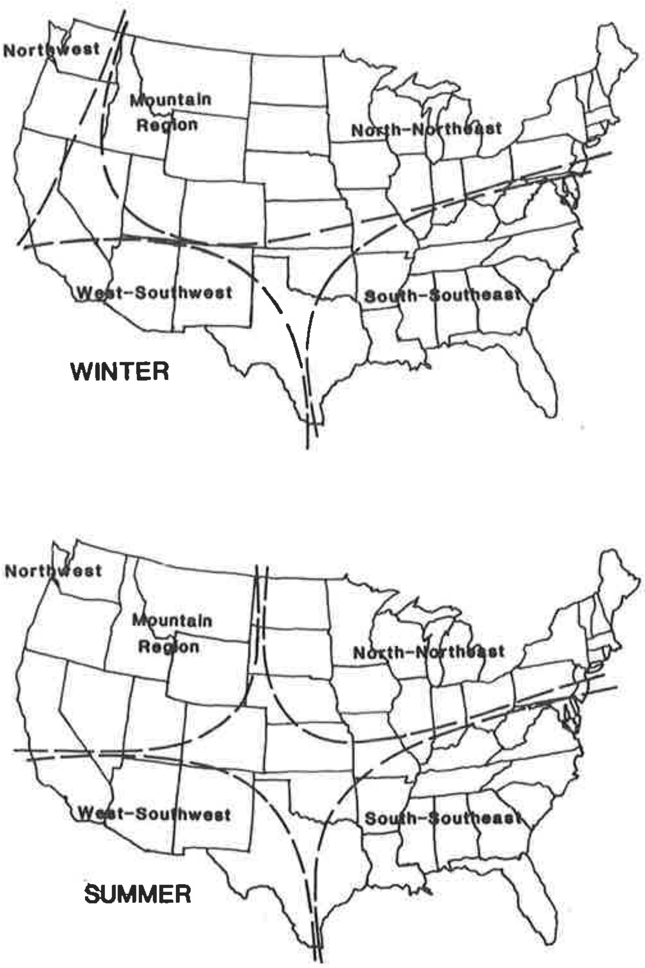


Figure 1. Regions with similar climates.

a. North-Northeast Region has severe winter conditions with most local areas experiencing biting cold temperatures for much of the winter. Average daily low temperatures range from 8 F to 20 F and maintenance personnel must prepare for considerable snow and ice. Summers, however, are moderate with average daily high temperatures of 85 F.
b. South-Southeast Region is characterized by hot and humid summers with temperatures ranging up to 95 F. Functioning air conditioning systems are mandatory in most areas within the region during the summer months. Winters are mild with occasional cold weather. Winter temperatures average in the high 30's and low 40's.
c. Southwest Region has summer climate that is very hot with temperatures frequently in excess of 100 F; however, since this is the arid portion of the country, humidity is very low. Winters are very moderate with average lows around 40 F.
d. Northwest Region climate is cool with considerable rain and fog. The northern portion receives considerable more rain than does the southern portion. Temperatures are moderate year round. Average winter low temperatures are around 40 F and summer temperatures rarely reach 90 F. Air conditioners are not required on buses in this region.
e. Mountain Region climate features low relative humudity and abundant sunshine. Winters are cold and stormy with mean temperatures ranging from 18 F to -40 F. Summer maximum temperatures can sometimes reach over 90 F. However; these temperatures are accompanied by low humidities which allow for comfort. Air conditioning systems on buses are optional in this region.

<u>Fleet Size</u>

Bus agencies were grouped into three size categories as follows:

a. Bus agencies with over 1,000 buses are considered for the purposes of this research project to be large. They are multi-facility agencies with considerable variations in their bus types. Many of the maintenance functions are centralized for economies in the work force and facility costs.

b. Agencies with bus fleets between 250 and 1,000 are grouped in the medium sized category. Within this group, some operate from a single facility, while others have multi-facilities as do the large properties.
c. Those agencies with less than 250 buses are considered to be small. While each may experience the same maintenance problems as the medium and large agencies, in many instances their size enables them to implement unique solutions to problems.

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 which have 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 usage by type of vehicle and by vehicle system. It was not expected that each agency could provide all of the data on every item.

**Selected Agencies**

Fifteen agencies representing a cross-section of the characteristics of bus transit properties were selected. An attempt was made to have a large, medium, and small agency from each of the climatic regions; however, it was not possible to find agencies in every region that could provide the required information. Figure 2 shows the geographical distribution of the selected agencies and the general characteristics of each agency are presented below.

North-Northeast Region

This 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).

Chicago Transit Authority operates 2300 diesel buses from 10 operating divisions with support from one central shop. The service is fairly low speed, and the terrain is considered flat. The area experiences wide variations in temperatures. The bus fleet is made up of M.A.N. articulated buses, GMC "new looks," and Flxible "new looks." Two hundred Flyer buses were purchased in late 1983 and were not included in the study because of insufficient data.

Southeastern Pennsylvania Transit Authority maintains over 1,450 transit buses in nine operating divisions supported by a single central unit rebuild and body shop. The terrain is relatively flat with some hilly areas, and the service is low speed. The bus fleet is made up of Flxible "new looks," RTS II's, GMC "new looks," and Neoplans. The Neoplan subfleet is new to the Authority and was not included in this study because of insufficient repair history.


Figure 2. Geographical distribution of selected agencies.

Ann Arbor Transit Authority operates 40 buses with a peak hour requirement of 36 buses. They are operated from an old facility that will soon be replaced with a modern, efficient facility. The fleet consists of "new look" GMC coaches, Grumman Flxible (GFC) 870's, and GMC RTS II buses. The terrain is moderately hilly.

Des Moines Metropolitan Transit Authority has a bus fleet of 85 diesel transit buses supplied by five different manufacturers. They include GMC "new looks," GMC RTS II's, GFC 870's, and American General (AMG) buses. All buses are operated from a single new facility. The maintenance philosophy at this agency requires that all mechanics be proficient at all maintenance tasks with little specialization.

South-Southeast Region

This region included the Washington Metropolitan Area Transit Authority (WMATA), the Regional Transit Authority (RTA), New Orleans, and the Austin Transit System (ATS).

Washington Metropolitan Area Transit Authority operates an active bus fleet of 1,652 vehicles from nine operating divisions supported by one large and one small central rebuild shops. Except for one new facility, the divisions are operating under crowded conditions. Present plans call for the replacement of four of the facilities in the near future and extensive renovations are underway at two others. The five different subfleets are GMC "new looks," Flxible (FLX) "new looks," AMG A model, RTS II's, and M.A.N. articulated buses. Most of the revenue service is operated in heavy traffic at slow speeds. A new fleet of Neoplan buses was not included in the study.

Regional Transit Authority, New Orleans has 463 buses in its bus fleet which includes GMC "new looks," GFC 870's, RTS II's, AMG, and FLX buses. The buses are operated at the slowest average speed reported on predominately narrow streets. The agency has a active program to upgrade its three facilities including central rebuild capability. The terrain is flat.

Austin Transit System operates 78 buses from a single modern facility. Its three subfleets are GMC "new looks," AMG A models, and TMC buses. The terrain is moderately hilly.

Southwest Region

Selected agencies in this region were the Southern California Rapid Transit District (SCRTD), the Orange County Transit District (OCTD), and the Albuquerque Transit System (ATS).

Southern California Rapid Transit District had the largest bus fleet in the study. Two-thousand six-hundred fifty eight active buses are maintained at 12 light maintenance facilities and one central maintenance facility. The agency has an on-going program to build new facilities and upgrade the existing ones. The fleet consists of a mix of GMC "new looks," RTS II's, AMG A and B models, GFC 870's, M.A.N. articulated buses, and M.A.N. double deckers. Since SCRTD provided the only data on double decker buses, these were not used in the study. The agency operates a variety of services from high speed express runs to slow line haul service. The terrain varies considerably from hilly to flat over the very large service area. The agency also is noted for its effort to provide a large number of wheelchair-equipped buses over a majority of its routes.

Orange County Transit District maintains 455 transit diesel buses at three modern facilities. Revenue service is at a relatively high speed, and the terrain is mostly flat. Manpower data from the RTS II's and FLX "new look" subfleets were used in the analysis, but a new group of Gillig Phantoms was excluded because they had not accumulated enough miles to provide meaningful data.

Albuquerque Transit System has a fleet mix of GMC "new looks," GFC 870's, and RTS II vehicles. All 107 of its buses are maintained at a single new facility. The terrain of the area was placed in the hilly category for the purposes of the analysis because many of the routes vary several hundred feet in elevation over their length.

Northwest Region

The agencies in this region were Seattle Metro (Metro), Tri-County Metropolitan Transportation District, Oregon (Tri-Met), and Salem Area Mass Transit District (SAT).

Seattle Metro has a total of 1,062 diesel transit buses, but only 827 are considered active. They are operated in hilly terrain from five divisions. This agency has the largest fleet of articulated buses as well as AMG and Flyer standard transit coaches. None of the buses have air conditioning systems. The average speed of the system is high.

Tri-County Metropolitan Transportation District, Oregon, reported 562 active buses stationed at three facilities. The service area is hilly, and the average revenue service is relatively high. The fleet mix is GMC "new looks," GMC RTS II's, AMG B models, FLX "new looks," and Crown articulated buses. Air conditioning systems are not in use.

Salem Area Mass Transit District operates 52 buses from a single site. The agency has a subfleet of GMC "new looks" averaging 17 years of service and new GMC RTS II's. The terrain is moderately hilly. Only a small number of the new buses are equipped with air conditioning systems.

Mountain Region

This region included the Regional Transportation District (RTD), Denver, and the Utah Transit Authority (UTA).

Regional Transporation District, Denver, operates a fleet of 744 buses consisting of GMC "new looks," AMG A and B models, MCI over-the-road coaches, FLX "new looks," and M.A.N. articulated buses. A small subfleet of vehicles used in a central business district transit mall shuttle operation was not included in the study. With the exception of one, all facilities are new and efficiently arranged. The terrain is considered as moderately hilly, and service is at a fairly high speed with a sizable number of peak-hour express runs. Air conditioners are not used except on a small number of buses.

Utah Transit Authority has a mix of AMG A and B models, GMC "new looks," GMC RTS II and FLX "new looks" in its 355 bus fleet. It has three light maintenance facilities and one support shop. Air conditioners are not included in bus equipment. The system speed is high, and the service area is moderately hilly.

## 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:

a. A listing of vehicle subsystems for which maintenance manpower was gathered.
b. Site-specific criteria which were anticipated to influence maintenance manpower.
c. 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 finalized. Most of the suggested changes were accommodated and the final listing was acceptable to the participants.

Air

The vehicle air subsystem included the air compressor, air piping and tubing, control cylinders, shift cylinders, air tanks, air governors, air gauges, safety valves, door interlocks, brake valves, quick release valves, brake diaphragms, air pressure regulator valves, air line shut-off valves, bus kneeling devices, and door regulator valves. Air starters are included for those buses so equipped.

Air Conditioning System

The air conditioning equipment included the compressor, condensor assembly, evaporator assembly, receiver, dryer, filters, piping, and cables.

Body

The vehicle body included the bumper assembly, exterior paneling, mirrors, windshield and frame, stanchions, seats, floor, floor covering, steps, doors, chimes or buzzer, windshield wipers, interior panels, and glass.

Drivetrain

The vehicle drivetrain consisted of the transmission, oil cooler, filters, hydraulic lines, governor, shift cable and linkage, speedometer drive, drive shaft, universal joints, flange, tube, differential, and rear axle.

Electrical

The vehicle electrical subsystem included the generator/ alternator, regulator, starter, battery, starter solenoid, vehicle lighting, signal lights, control switches, solenoids, control interlocks, horn, and electrical cabling and wiring.

Engine

The engine assembly included engine cradle, blower, flywheel and housing, engine governor, crankshaft, oil pump, valve covers, heads and valves, injectors, timing gears, camshaft and valve mechanism, oil gauges, oil filters, oil pan, damper, muffler, tail pipe, air cleaners, air intake manifold, injectors, fuel lines, fuel pump, fuel tank, and fuel filters. Turbo chargers are included if so equipped.

Heating and Ventilation

The vehicle heating and ventilation equipment included the operator's heating unit, defroster, passenger heating units, water modulation valves, and gradustat.

Steering

Vehicle steering included the steering wheel, steering column and boxes, steering driveshaft, drag links, tie rods and ends, and power steering pump.

Suspension

The suspension subsystem was made up of bellows supports, bellows, shock absorbers, radial bars, lateral bars, and stabilizers.

Wheel and Tires

This vehicle assembly included hubs, bearings, seals, wheels, and tires.

Vehicle Accessories

Four vehicle accessories are included in this study. They are destination signs (electronic or curtain type), fareboxes (registering or nonregistering), radios, and 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:

a. Climate.
b. Terrain.
c. Multi-facility.
d. Fleet composition.
e. Fleet age.
f. Operating speed.
g. Work rules.
h. Local policies.

Climate

The effect of climate was expected to have a significant impact on the manpower required to maintain air conditioning equipment in the hot regions of the country and heating equipment in those areas which experience harsh winters. Additionally, 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 with flat terrain. Brake life may also be affected. Other areas are not 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.

Multi-facilities

Large agencies must build light maintenance facilities at different locations within their service areas in order to minimize the cost of deadhead time and miles. This policy results in more demands on maintenance manpower for additional supervision and, in some instances, repair specialists. However, some economies may be realized by centralizing component rebuilding and body repairs.

Fleet Composition

Public agencies are required to have many different types of buses in their fleet to satisfy different service requirements. These may include:

a. For circulator service, 30 to 35-ft buses.
b. For local line-haul as well as express service, 40-ft standard coaches.
c. For heavily patronized local and express routes, 55 to 60-ft articulated buses.

With competitive bidding procedures in place throughout the country, an agency may also have buses from several manufacturers in each type. Each has unique maintenance requirements that must be considered in manpower planning.

Fleet Age

As vehicles accumulate service miles/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 agressive preventive maintenance programs and replacement/repair of worn or failed components.

Operating Speed

The average operating speed in revenue service was used as the determining factor to learn if buses operating over routes with low average speeds require more maintenance than those with higher speeds.

Work Rules

Work rules may have a significant impact on maintenance manpower. Nonproductivity time for such items as coffee breaks and clean up time may be as high as 15 percent of the work day at some agencies. Additionally, skill restrictions as the result of union contracts or past practices may increase manpower needs.

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, while others schedule buses through the body shop periodically to repair accumulated dents and paint scratches. Additionally, the level of cleanliness policy may be reflected in man-hours devoted to major cleaning activities.

**Data Collection Guide**

A well-structured data collection guide was considered mandatory for this 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 which is presented in (Appendix B) was organized into seven sections:

a. General agency information.
b. Maintenance staffing information.
c. Maintenance manpower data.
d. Major work activities.
e. Bus subfleet profile.
f. Vehicle systems data.
g. Standard glossary of terms.

General Agency Information

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

a. Total annual miles operated.
b. Revenue service miles.
c. Revenue service hours.
d. Peak period requirements.
e. Base period requirements.
f. Active bus fleet.
g. Spare buses.
h. Weekend service requirements.
i. Facility information.
j. Vehicle accident statistics.
k. Road calls.
l. Wheelchair lift policy.

Maintenance Staffing Information

Detail maintenance staffing for the agency was 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.

Maintenance Manpower 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 significant impact on total manpower levels.

Major Work Activity

Preventive maintenance inspections and servicing/cleaning of buses require significant amounts of manpower; however, manpower information was not reported by vehicle subsystem.

Bus Subfleet Data

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

Vehicle Systems Data

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

**Standard Glossary of Terms**

A clear definition of transit industry terms by the members of the research team was important. Thus, prior to scheduled visits, the glossary in Appendix B 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 if there were any differences that need to be considered during the data analysis.

### Data Collection Procedure

Actual data collected using the guide was handled by visits to each agency by a member of the study team. Well in advance of their 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 statistical techniques for compiling and evaluating the maintenance manpower data collected from the selected bus agencies was comprised of three primary elements:

a. A technique for building up maintenance manpower requirements based on disaggregate work activities by subfleet and functional area.
b. A series of statistical applications to compare the range of maintenance requirements (e.g., hours to repair and frequency of repair by vehicle system and subfleet) as determined in the data collection activity.
c. Procedures for evaluating the factors which account for major variances in time to repair and frequency of repair by vehicle system and subfleet.

### Build Up Manpower Requirements

The technique for building 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 are 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 build-up technique was comprised of five key steps:

a. Line work-hour requirements were estimated separately for four maintenance functions including Inspections, Component Rebuild and Heavy Repair, Running Repair, and Cleaning and Servicing.
b. Work-hour requirements were expanded by scheduled and unscheduled labor-hours unavailable for work.
c. Line staff hours were reduced by overtime hours to determine total regular man-hours (e.g., to normalize hours for calculating staffing levels).
d. The estimate of regular man-hours was compared to the actual figure and all differences reconciled.
e. Supervisory requirements were estimated.

These steps were consistently applied at each individual transit agency upon completion of the data collection activity. This served to maximize productive utilization of team resources and facilitated timely completion of the study overall.

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: Inspections, Component Rebuild and Heavy Repair, Running repair, and Cleaning and Servicing. Line work-hour requirements represented those hours spent performing maintenance tasks that could be accounted for by a transit agency. Hours estimation was similar for each function with job times and frequency driving labor-hour needs; however, the specific computations did vary somewhat with regard to specific algorithms. These are discussed, by function, below:

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 the repetitive and routine nature. The primary formula for determining the amount of work-hours expended on inspection is given in Eq. 1.

$$\sum_{i}\sum_{j} \text{Hours to Perform}_{ij} * \left(\text{Annual Miles}_{j} \Big/ \text{Miles Between Inspections}_{ij}\right) \quad (1)$$

Where:
i = Inspection type (e.g., safety)
j = Vehicle type (e.g., by subfleet)

It was important to include only hours spent on inspection in this calculation to maintain comparability between properties (some agencies include running repair times in inspection, while others do not). Hours spent on light repair work during scheduled inspections were included in Running Repair estimates. Total annual inspection hours are found by summing hours for all inspection types across all subfleets.

Component Rebuild and Heavy Repair. The unit rebuild function was characterized by routine activities that were relatively straightforward to analyze. Estimation of labor-hours expended on rebuilds was determined by obtaining average times to rebuild major components and the average life of the component reported by the agency using Eq. 2.

$$\sum_{k}\sum_{j} \text{Hours to Rebuild}_{kj} * \left(\text{Annual Miles}_{j} \Big/ \text{Miles Between Rebuilds}_{kj}\right) \quad (2)$$

Where:
j = Vehicle type (e.g., by subfleet)
k = Vehicle component or unit

All remove and replace times for component rebuilds were placed under running repair and not included in this part of the analysis. Further, for the purposes of this analysis, major repair hours (e.g., body and paint) were included in heavy repair. The formula for body, paint, upholstery, and glass repair activities is given in Eq. 3.

$$\sum_a \sum_j \text{Annual Hours per Bus}_{aj} * \text{Number of Buses}_j \quad (3)$$

Where:
a = Type of activity (e.g., body)
j = Vehicle type (e.g., by subfleet)

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 using Eq. 4.

$$\sum_i \sum_j \text{Inspection Time Spent on Repair} * \left( \text{Annual Miles}_j \Big/ \text{Miles Between Inspections}_{ij} \right) \quad (4)$$

Where:
i = Type of inspection (e.g., safety)
j = Vehicle type (e.g., by subfleet)

Second, running repair time spent on removal and replacement of major vehicle components was estimated using Eq. 5.

$$\sum_k \sum_j \text{Remove and Replace Time}_{kj} * \left( \text{Annual Miles}_j \Big/ \text{Miles Between Rebuilds}_{kj} \right) \quad (5)$$

Where:
k = Vehicle component or unit
j = Vehicle type (e.g., by subfleet)

Third, all other running repair time was estimated using Eq. 6.

$$\sum_s \sum_j \text{Annual Running Repair Hours Per Bus}_{sj} * \text{Number of Vehicles}_j \quad (6)$$

Where:
s = Vehicle system
j = Vehicle type (e.g., by subfleet)

Total man-hours spent on running repair was found by totaling the results of the three algorithms.

Cleaning and Servicing. The formula for estimating man-hours expended in this activity follows in Eq. 7.

$$\sum_c \sum_j \text{Servicing Hours Per Bus}_{cj} * \text{Number of Annual Vehicles Serviced}_{cj} \quad (7)$$

Where:
c = Type of service activity
j = Vehicle type (e.g., by subfleet)

Daily vehicles serviced were determined using average weekday, Saturday and Sunday vehicles dispatched, and the number of days each of these schedules operated in the year. The average time required to take a bus through the complete servicing and cleaning cycle was estimated and applied to the frequency for the activity. Major cleaning activities generally occurred on a regular, although less frequent, basis. The number of vehicles cleaned was estimated using the active fleet size and the number of cleanings per vehicle per year.

Total Line Work-Hours. Total worked hours were found as the sum of hours deployed in each of the four functional areas discussed above. It is important to note that many of the survey agencies did not assign manpower exclusively to one maintenance function. Because of this, mechanic hours (e.g., inspecton, rebuild, and running repair) were totaled for comparison with actual staffing levels. In all cases the cleaning and servicing function had a dedicated staff, so they were totaled separately.

Expand Worked Hours

Total hours expended on work activities were expanded by scheduled and unscheduled labor-hours unavailable for maintenance activities. Scheduled unavailable time included vacations, holidays, paid lunch and/or coffee breaks, 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. While these hours did not contribute to the conduct of maintenance activities, they did expand the size of the staff needed to perform maintenance activities. The activities were reported in terms of annual hours. Where the number of days per employee per year was used, this was translated to annual hours assuming a standard eight-hour day.

Equation 8 provides the formula used for expanding work-hours for unavailable time on the job (i.e., to reflect the real work day) as follows:

$$\text{Annual Worked Hours} * \left\{ 8 \text{ hours} \Big/ \left[ 8 \text{ hours} - \left( \sum_d \text{Break Hours}_d \right) \right] \right\} \quad (8)$$

Where:
d = Type of break (e.g., coffee, paid lunch, clean up time)

Workday hours were then expanded using Eq. 9 for unavailable time not at work as follows:

$$\text{Annual Work Day Hours} \quad * \quad \left\{260 \text{ days} - \left[260 \text{ days} - \left(\sum_{e} \text{Days not at work}_e\right)\right]\right\} \quad (9)$$

Where:

e = Type of absence (e.g., holiday, vacation, sick, etc.)

This yielded total expanded man-hours for maintenance functions and was an attempt at accounting for all uses of maintenance manpower.

Reduce Expanded Hours by Overtime

The previous step resulted in an increased need for maintenance employees. Overtime actually reduced the number of employees needed to perform work activities and it was important to note this characteristic prior to estimating maintenance manpower from the annual expanded hours. The formula in Eq. 10 used here was:

$$\text{Expanded Hours} \; * \; (1 - \text{Proportion Overtime Worked}) \quad (10)$$

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 regular man-hours for maintenance line staff. Actual regular man-hours was determined by multiplying total staff by 2,080 hours 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 with other agencies.

There were several areas that 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 into supervision. Another area was small unreported jobs (e.g., valve rebuilding in Component Rebuild) which, 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 included in the estimated figure. This required going back through the previous estimation steps.

If a difference existed between the estimate and the acutal figure and could not be reconciled, the amount was handled as a lump sum representing other unaccounted hours and the estimate adjusted accordingly. The normalized hours were divided by 2,080 to yield manpower requirements.

Determine Supervisory Needs

Supervisory and management needs can be expressed as a proportion of either line staff hours or manpower. The calculation (Eq. 11) was as follows:

$$\text{Supervisory Ratio} \quad * \quad \text{Line Staff Requirements} \quad (11)$$

If the supervisory ratio varied substantially between properties, other influencing factors (i.e., number of facilities) were evaluated. For example, many agencies used senior mechanics as working supervisors. If master mechanics were used in supervision, the calculation in Eq. 12 was based on hours as follows:

$$\left(\text{Total Line Staff Hours} - \text{Hours Spent Supervising}\right) \; * \; \text{Supervisory Ratio} \quad (12)$$

**Comparative Analysis Of Results**

After manpower requirements were built up 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 subsystem and included job performance and frequency parameters. In addition, more aggregate manpower requirements were compared (e.g., proportion of labor resources by subsystem, unavailable time, overtime). The primary tools of comparison were the mean and standard deviation (using n - 1 weighting to account for the limited sample size) for all the variables. Each of the statistical applications is discussed below.

Mean

The average (e.g., mean) value of all primary manpower parameters collected at the agencies and identified in the build-up procedure were determined by adding like values across all subject agencies and dividing the sum by the number of agencies tested. The formula (Eq. 13) for calculating the mean value was:

$$\text{Mean}_{pj} = \left(\sum_{a=1}^{n} \text{Value}_{pa}\right) \Big/ n \qquad (13)$$

Where:

p = Manpower parameter
a = Transit agency
n = Number of transit agencies in test
j = Vehicle type (e.g., subfleet)

The mean value provided a norm or expected value for each parameter in the analysis.

Standard Deviation

The standard deviation of manpower parameters provided a normalized range of experience at the subject transit agencies using the mean value as a point of reference and n - 1 weighting to account for the constrained sample size. The standard deviation is a commonly used statistical formula and is shown in Eq. 14.

$$\text{Standard Deviation}_{pj} = \sqrt{\sum_{a=1}^{n} \frac{(\text{Value}_{pa} - \text{Mean}_{pj})^2}{n-1}} \quad (14)$$

Where:

p = Manpower parameter
a = Transit agency
n = Number of transit agencies
j = Vehicle type (e.g., subfleet)

The standard deviation provided an indication of the normalized range of the actual values for parameters influencing maintenance manpower requirements. It is not to say that all data points fell within ± one standard deviation, but rather that 68.26 percent of transit agencies are expected to fall within the range specified. It also served to identify those areas which required more detailed analysis due to high variability.

### Evaluate Impact Of Independent Factors

The scope and scale of analysis in this activity was a function of the results of the previous task. Because this research activity was unique, there was no past experience which would suggest probable outcomes of the comparative analysis. Although the actual parameters to be evaluated were not known at the study onset, the techniques for evaluating the impact of independent factors were regression analysis, correlation analysis, and factor impact analysis. Independent variables with a potential impact on manpower requirements were identified by the research team based on prior experience and maintenance expertise, and examined for those areas exhibiting labor variations amongst agencies.

Regression Analysis

The study team utilized simple and/or multiple regression analysis to determine the impact of independent factors on manpower parameters where some correlation between the variables was apparent. The mathematical formula (Eq. 15) for regression analysis was:

$$y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + e \quad (15)$$

Where:

$y$ = Manpower parameter (dependent variable)

$x_n$ = The $n^{th}$ independent variable (may be one factor or more as shown above)

$b_o$ = Intercept on the manpower parameter

$b_n$ = Coefficient of impact of the $n^{th}$ independent variable

$e$ = The residual, or change in the manpower parameter not accounted for by the independent variable(s)

While the regression equation was important overall, the audience for which the final study results are intended may prefer visual representations of factor impacts. To accommodate this need, the subject manpower parameter was plotted against the primary independent factor, and secondary factor where appropriate, to illustrate the magnitude of impact.

It is important to note that simply plotting the absolute value of dependent and independent variables for each agency did not generally produce lines intersecting zero on both axes. In many cases, the "Y" intercept was well above all of the five small agencies, which presented a problem with evaluating the lower end of the agency scale. To overcome this problem, the regression analysis was conducted utilizing the relationship of the dependent and independent variables for each agency, and a mean and standard deviation developed across all agencies. For example, annual man-hours per 100,000 vehicle-miles for a particular function was calculated and plotted for each individual agency. The mean and standard deviation of this relationship were determined and are presented in the figures in Chapter Two in numeric form. The results of this analysis (e.g., the mean and standard deviation of man-hours per 100,000 vehicle-miles) were then applied to the range of characteristics prevailing in the sample group (e.g., total annual miles). This approach always produces a line with the intercept 0,0. The mean line and standard deviation are presented graphically in terms more easily understood by maintenance managers. The advantages of this approach include better representation of all agencies and results that are easy to understand for the nonstatistician. The major drawback is that this results in slightly higher standard deviations (i.e., the new mean is compared to the actual values for dependent and independent variables).

Another important consideration is the relationship of the variables over the magnitude of the scale. All of the relationships presented in this report take the form of a line. In analyzing the actual data points, the research team applied five different types of functions to each maintenance activity, including a constant curve, a line, a logarithmic curve, a parabola, and a sine curve. In fitting each curve, the research team evaluated the normalized standard error of the data points to select the "best fit." In almost every case, the curve exhibiting the lowest normalized standard error was a line. In a few instances (i.e., inspection hours and wheelchair lifts) there was little conformity to any of the curves. To preserve consistency, these were also depicted using a line.

Coefficient of Correlation (r)

After completing the regression computation, the coefficient of correlation was used as a check to ensure that the variation in the maintenance parameter was sufficiently explained by the independent factor(s). The r factor was a measure of the deviation in the parameter due to the regression divided by the deviation about the mean. The calculations were tedious, and were best accomplished using a standard statistical software package and a microprocessor; therefore, it is not necessary to delve into the mathematical equation for the measure.

Factor Impact Anaylsis

Upon satisfying correlation requirements, the research team then defined the relative impact of independent factors on specific manpower parameters relative to the change in the independent variable. The impact was expressed as a proportion or percentage change in the parameter. For instance, if a relative impact factor of 0.50 was found in assessing the impact of mechanic experience on the time it takes to reline the brakes on a particular type of bus, then 50 percent of the time required to reline those brakes was directly related to the experience of a mechanic.

This technique was also applicable to multiple regression or multiple factor impacts. Assuming a relationship between the frequency of a repair (dependent parameter) and fleet age and vehicle utilization (independent factors), the aggregate impact of these factors was investigated.

While those were the basic tools for analyzing the impact of factors (e.g., climate, vehicle speed,mechanic experience) on manpower parameters (e.g., time and frequency of repair by vehicle system by subfleet), the results of the comparative analysis, coupled with the investigator's prior experience, drove the actual parameters and factors which underwent evaluation.

**ORGANIZATION OF THE REPORT**

This report has been prepared to document the approach, findings, conclusions and applications of the project results. This chapter has presented a brief overview of the research objectives and approach. The remainder of the report is organized as follows:

a. Chapter Two reviews the maintenance manpower findings and includes detailed descriptions of labor utilization by activity area and the causal factors driving differences between the subject agencies.
b. Chapter Three presents the maintenance manpower planning model, including graphic and algebraic solutions developed as a result of the research, and discusses its use.
c. Chapter Four discusses the conclusions of the research and areas where more investigation is warranted.
d. Appendix A demonstrates application of the maintenance manpower planning model at a hypothetical agency in both graphical and algebraic form.
e. Appendix B contains the data collection guide and glossary of terms used to glean disaggregate manpower information from the subject agencies.

CHAPTER TWO

# FINDINGS

**DATA AVAILABILITY**

During the initial phase of the study public transit agencies were contacted by telephone to solicite their cooperation. The overall response was very favorable, and the need for the product of the study was confirmed by maintenance managers. During the initial contacts a general understanding of the characteristics of each agency was obtained for use in selecting a representative cross-section of operators. The availability of existing manpower data was given high priority since the funds to conduct the study were limited and the agencies could be expected to devote little of their resources to assist the study team.

### Data Systems in Transition

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 underway for a number of years, the pace has quickened with many of the industry leaders reporting that their systems became operational only during the past two years and development of all system elements is not yet complete. The low cost of microprocessers 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 with some joined together 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 underway 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.

### Manpower Reporting Systems Limitations

Only 18 agencies stated that their reporting systems could generate data of the type needed for the study and none could provide all of it. The major defficiency 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 could not by vehicle subfleet.

Another major defficiency 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 of components at failure. This important data element was obtained in most instances through inventory control records which documented the number of units issued to buses.

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

## MANPOWER REPORTED

Maintenance personnel shown in transit agency budgets and organization charts were generally found to have many work assignments in addition to maintaining and servicing transit revenue vehicles. Before evaluating a particular agency's staffing levels, the major work assignments, other than those related to revenue vehicle maintenance, were identified and staffing requirements for those removed. This allowed for an equitable comparison of the model's results and actual maintenance staff by function.

### Cleaning and Servicing

These personnel had many varied assignments. At some agencies these personnel performed routine janitorial services in addition to their normal assignments, while at others separate groups would carry out this work. Cleaning/service 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 defects reports received from bus operators. Also, large transit agencies used service personnel to move vehicles between divisions when short falls occurred.

The small agencies were able to account for over 92 percent of their service and cleaning manpower. The work crews are smaller and easier to supervise. Additionally, the time to circulate buses through the cleaning/servicing cycle was better known in the single facility agencies.

Medium size and large agencies accounted for 82 percent and 83 percent of their service/cleaning man-hours respectfully. These numbers are considered to be quite good since they were based in large part on an average time to take a bus through the service and cleaning cycle. The number of bus maintenance facilities at these agencies varied from as few as 3 up to as many as 12. Each had different circulation and parking arrangements with varying time requirements. The average time requirements determined were generally extrapolated from a single representative division's experience.

### Maintenance

In addition to 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 ranging from electric trolley buses, trolley cars, para-transit vans, and specially equipped vehicles for handicapped passenger service. 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 fixed. Additionally, each of these operators had a single maintenance facility.

Medium size agencies accounted for 78 percent of their maintenance time and large agencies reported 75 percent respectively. Most maintenance managers and supervisors stated that the primary contributor to unreported time was in 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.

### Manpower Distribution

Overall the agencies accounted for an average 82 percent of their available manpower. The distribution of the manpower as estimated by function and subsystem is shown in Table I. The manpower variances and independent factors influencing those variances are detailed in the following section.

Table I
Distribution of Manpower

| Work Function/System | Percent of Manpower |
|---|---|
| Service/Cleaning | 21 |
| Body Repairs | 21 |
| Inspections | 12 |
| Engine/Fuel | 9 |
| Braking | 7 |
| Electrical | 6 |
| Air | 5 |
| Air Conditioning, Heating, Ventilation | 5 |
| Drive-train | 5 |
| Accessories | 5 |
| Cooling | 3 |
| Wheels, Tires | 1 |
| | 100 |

## MANPOWER VARIANCES

Taken at an disaggregate level, the manpower requirements for maintaining revenue vehicles varied considerably among the transit agencies investigated in this research program. However, when analyzed at a more aggregate level (i.e., maintenance function and vehicle subsystem), factors causing the manpower differences become apparent, and labor requirements are relatively congruous. This section presents the results of the research into manpower variances by maintenance function and subsystem.

At the study's onset, the investigators identified a rigorous list of potential independent variables influencing maintenance manpower requirements based on professional experience and expertise. These independent variables were then evaluated using standard statistical techniques to verify or refute initial expectations. The primary tools used to analyze potential causal factors included correlation, regression, factor impact, and standard error analyses. Once a significant relationship between the manpower requirements and an independent variable was identified, the mean and standard deviation (using n - 1 weighting to account for the constrained sample size) of the relationship was determined. Additional telephone interviews were conducted with the survey agencies to further explain significant deviations in manpower use to identify additional variances and/or data inaccuracies.

The manpower requirements relationships and variances are presented both numerically and graphically. The analytic technique, discussed previously in Chapter One, entailed development of the mean relationship between independent (e.g., vehicle-miles) and dependent (e.g., man-hours) variables, and analysis of the standard deviation (i.e., ± one standard deviation) from the mean relationship. These values are shown numerically for each maintenance activity in corresponding exhibits. The mean and standard deviation of the relationships were then applied to the characteristics of the study group and displayed graphically for ease of comprehension. The line(s) in each figure represent the mean value, and the shaded area is used to indicate the boundaries of ± one standard deviation.

### 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. Most of the agencies surveyed have three primary activities for cleaning and servicing staff: daily servicing, major interior cleaning, and chassis wash. Of the three, daily servicing accounted for the majority of staff time. On the average, cleaning and servicing accounted for 21 percent of maintenance man-hours, and ranged from a low of 5,600 hours to a high of 272,350 hours per annum. The primary factor influencing the difference in man-hours is the scale of operations, expressed as the agency's number of peak vehicles.

The coefficient of correlation (i.e., r) between peak vehicles and man-hours for cleaning and servicing was 0.87, leaving a normalized standard error of 13 percent. The additional variation in man-hours was attributed to policy differences in the frequency of cleaning activites (i.e., particularly between major interior cleanings which ranged from bi-weekly to once every three months) and the relative efficiency of facilities.

On the average, the agencies surveyed required 138.5 man-hours per peak vehicle per year for servicing and cleaning, as shown in Figure 3. The standard deviation was ± 19.9 hours per peak vehicle with the difference 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 separate buildings and enter a public street between each during the daily servicing cycle. This extended the time required to perform a daily servicing, and placed the property in the upper range of manpower requirements. Similarly, most agencies surveyed conduct a major interior cleaning on every active vehicle once a month. One property conducted major interior cleanings only once every three months, and subsequently appeared in the lower range of manpower requirements.

### Body

The body subsystem is comprised 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 hours to 365,750 man-hours per year in the study group. The amount of man-hours devoted to body repair is a function of vehicle-miles (e.g., exposure), accident rates, and policy regarding acceptable vehicle appearance.

The coefficient of correlation between vehicle-miles and man-hours required for body repair was 0.65, leaving 0.35 of the change in man-hours unaccounted for by vehicle-miles. Because of the low correlation, body man-hours were further investigated. As the result of the analysis, accidents were identified as another significant factor influencing body man-hour requirements. Together, vehicle-miles and accidents, account for 91 percent of the variation in man-hours, (i.e., r = 0.91) leaving only 9 percent of the variation unaccounted for by vehicle-miles and accidents. This remainder may be attributable to policy regarding acceptable vehicle appearances (e.g., painting frequency) and campaigns to improve vehicle appearance.

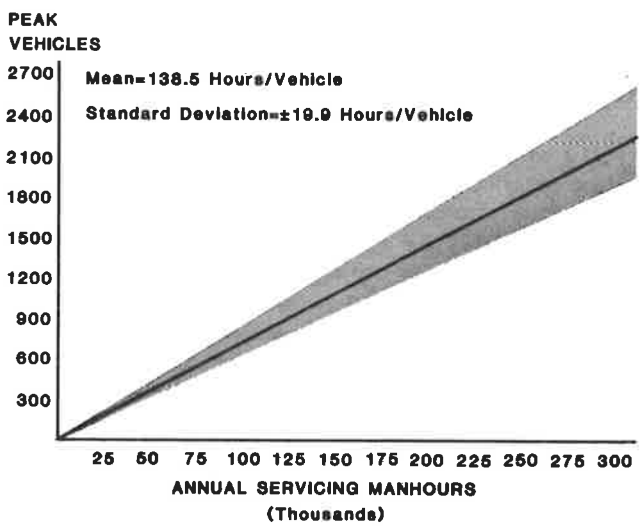


Figure 3. Servicing and cleaning man-hours.

On the average, the survey agencies required 220 man-hours for body repair per 100,000 miles, as shown in Figure 4. The standard deviation was ± 76.5 hours per 100,000 miles. The survey agencies also had an average of 40 accidents per million miles. Man-hour requirements per 100,000 miles for body repair were lower for properties with lower accident rates, and higher for properties incurring accidents at a higher rate. On the average, properties required 5.5 hours per 100,000 vehicle-miles for body repair for each accident per million miles, as shown in Figure 5. A property with 40 accidents per million miles would be expected to require an average of 220 man-hours per 100,000 miles. There was a standard deviation of ± 1.5 hours per 100,000 miles for every accident per million miles. This deviation is primarily attributable to local policy. A property with a high priority on vehicle appearance would fall in the upper range (e.g., 7.0 hours per 100,000 vehicle-miles), while a system with a lower priority, would fall into the lower range (e.g., 4.0 hours per 100,000 vehicle-miles).

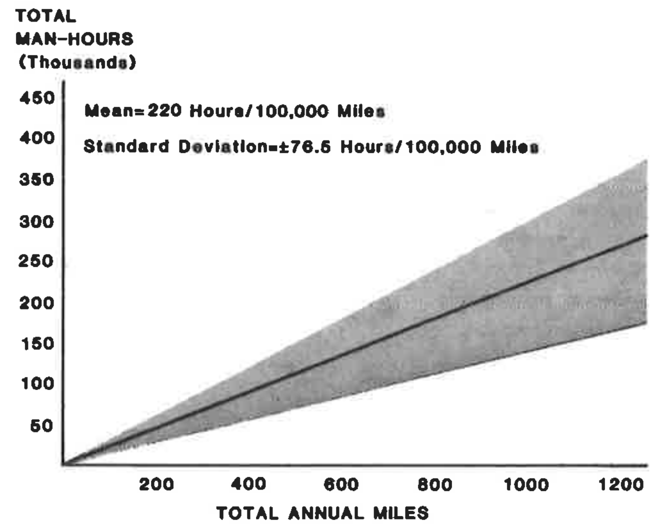


Figure 4. Body man-hours.

## Inspection

The inspection function is generally comprised of a number of inspection types (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 hours to 166,000 hours. On the average, inspections accounted for 12 percent of total maintenance manpower, but varied significantly by transit agency. The primary reason for differences in this manpower category is local maintenance philosophy regarding inspection.

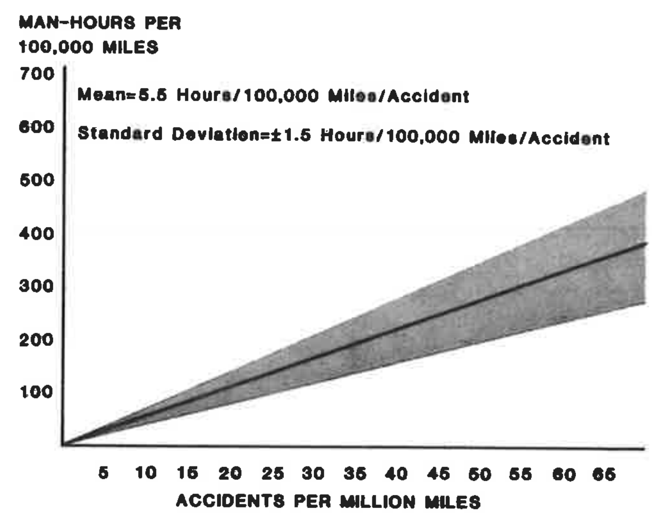


Figure 5. Accident rate effect on body man-hours.

The coefficient of correlation between inspection man-hours and vehicle-miles was only 0.20, leaving 80 percent of the change in man-hours not accounted for by vehicle-miles. Similarly, low correlations were found between inspection frequencies and manpower requirements. No independent variable was identified as having a significant effect on inspection hours. Some agencies have time consuming statutory inspections, while most have none. Some agencies have several types of safety inspections, while others only use minor and major inspections. Further, some agencies devoted 50 percent of inspection time to running repair, while other agencies allowed no running repair during inspections.

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

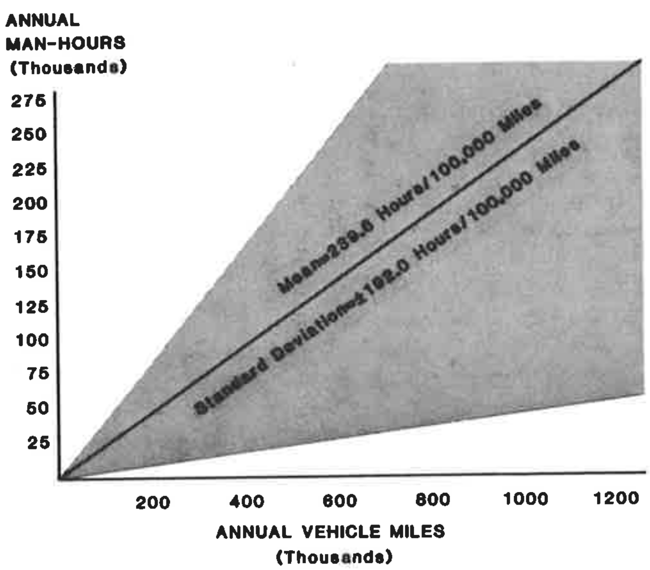


Figure 6. Inspection man-hours.

## Engine and Fuel

Initially, the research team attempted to evaluate engine and fuel repair separately. This proved impractical, because many of the subject properties combined these functions into one subsystem for internal records. The engine and fuel subsystem as analyzed in this study is comprised of repair, remove and replace, and rebuild times for the following components:

a. Engine.
b. Engine cradle assembly.
c. Engine head.
d. Engine blower.
e. Engine turbocharger.
f. Fuel pump and injectors.
g. Fuel tank.

Engine and fuel man-hours accounted for an average of 9 percent of maintenance man-hours, and ranged from 2,460 hours to 191,200 hours 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 0.76, leaving 24 percent of the variance not accounted for by vehicle-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 (i.e., r = 0.95). 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 expended 157 man-hours per 100,000 vehicle-miles on engine and fuel maintenance, as shown in Figure 7. The standard deviation was ± 38.4 hours per 100,000 vehicle-miles. Most of this deviation was attributable to the fleet mix, as illustrated in Figure 8. Depending on the vehicle accumulating miles, engine and fuel man-hours ranged from a mean of 130 (e.g., GMC) to 229 (e.g., M.A.N.) hours per 100,000 vehicle-miles. Interestingly, the two outlyers in terms of standard deviation (e.g., GFC with ±46, and M.A.N. ±136 man-hours per 100,000 vehicle-miles) each had the smallest sample size: four agencies each. The remaining subfleets had between 8 and 12 survey properties each.

Some caution must be exercised in reviewing subfleet labor requirements. These numbers are based on the experi-

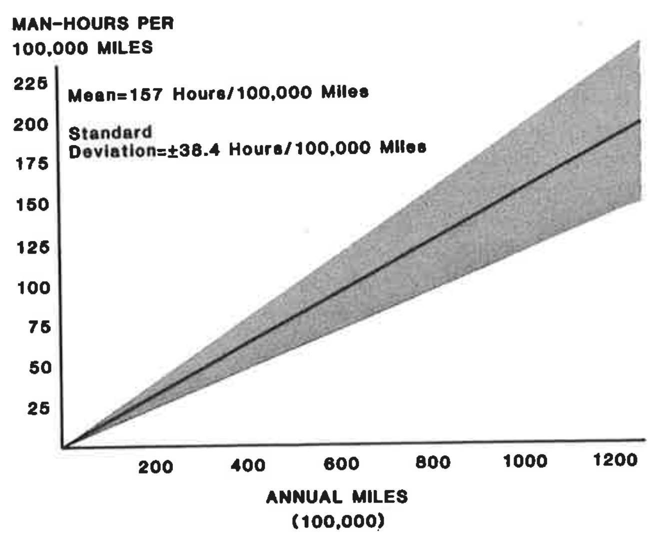


Figure 7. Engine and fuel man-hours.

ence of 15 transit agencies as reported to the research team. The differences displayed in Figure 8 illustrate what differences exist and not why. Subfleet line speed, mechanic training, vehicle age, facilities, and equipment may all impact man-hour requirements. For example, the M.A.N. articulated vehicle exhibited both the highest mean time for maintenance and the largest standard deviation.

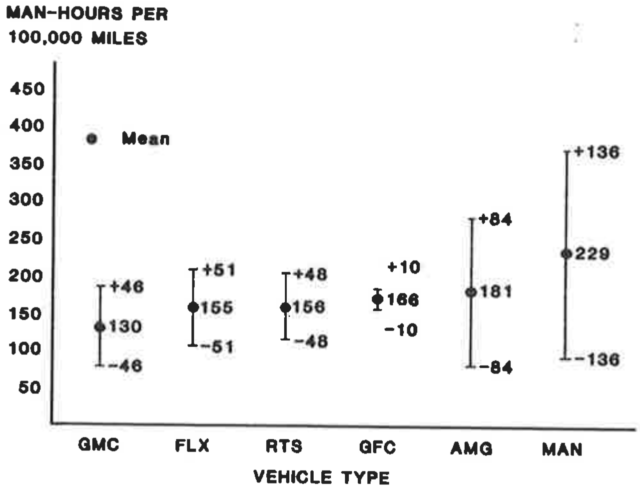


Figure 8. Engine and fuel man-hours by vehicle type.

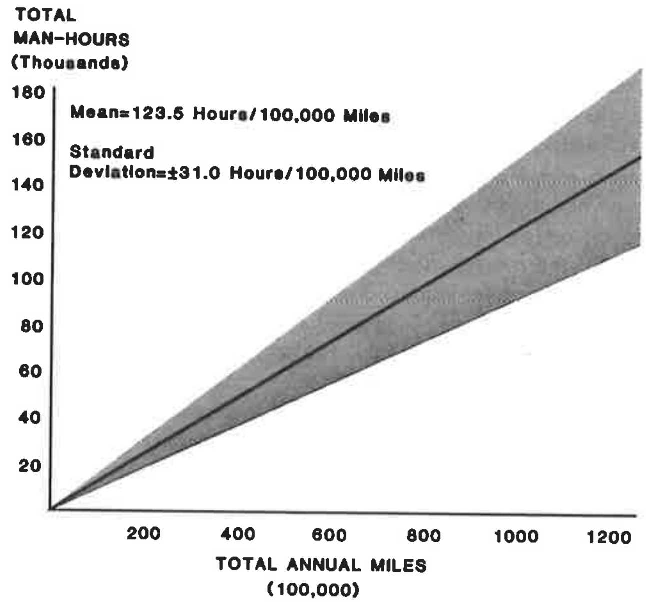


Figure 9. Braking man-hours.

Further investigation revealed that two properties at the upper end 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 properties on the lower end of the scale were using the vehicles exclusively in high speed service. Because line speed data were not available 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 comprised 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 hours to a high of 132,000 hours per year in the survey group. The primary factors accounting for the difference in man-hours are miles of operation, line speed, and vehicle type.

The coefficient of correlation between braking hours and vehicle-miles was 0.75, leaving 25 percent of the deviation not accounted for by vehicle-miles. When supplemented with average systemwide speed, the correlation rose another 0.03 to 0.78. 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 0.88. 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 evaluting mathematical relationships between these variables was not possible.

On the average, transit agencies required 123.5 hours per 100,000 vehicle-miles to make brake repairs, as illustrated in Figure 9. The standard deviation was ± 31.0 hours per 100,000 miles. The majority of this deviation is accounted for by vehicle type (i.e., manufacturer). The range reported by fleet manufacturer, shown in Figure 10, spans from a low of 102 man-hours per 100,000 miles for Flxibles to a high of 158 man-hours per 100,000 miles for GFC's. The standard deviation by subfleet averages ± 58 man-hours per 100,000 miles, with RTS at the low end (± 23 man-hours per 100,000 miles) and M.A.N. at the high end (± 80 man-hours per 100,000 miles standard deviation).

While numerical values were not available for terrain, properties with hilly and/or mountainous terrain placed on the high side of the mean for each vehicle type. Correspondingly, agencies with flat terrain generally fell on the low side of the means. 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 properties with M.A.N. articulated vehicles did identify relative speeds for these vehicles. Two operators used the M.A.N.'s exclusively in low speed service, and both appeared

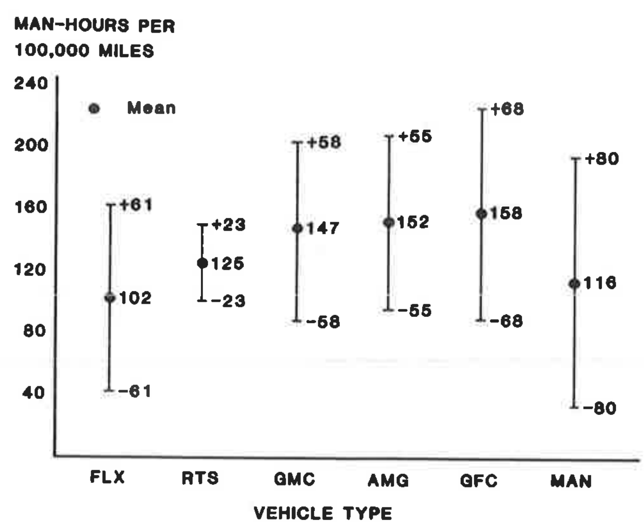


Figure 10. Braking man-hours by vehicle type.

well above the mean hour requirement. The other two operators used these vehicles exclusively 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 levels, and facility and equipment adequacy.

## Electrical

The electrical subsystem is comprised of running repair, remove and replace and rebuild activities for starters, alternators/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 0.75, leaving 26 percent of the variation not accounted for by miles. When the secondary variable of vehicle type is also evaluated, correlation rises to 0.95, leaving a standard error of only 5 percent. Both climate and speed were evaluated as potential independent variables, with no significant correlation found.

On the average, the survey agencies required 93 hours per 100,000 miles for electrical repair, as illustrated in Figure 11. The standard deviation was ± 24.5 hours. Most of this deviation is explained by vehicle mix, as shown in Figure 12. Electrical man-hour requirements ranged from an average of 92 hours per 100,000 miles for RTS vehicles to an average of 147 hours per 100,000 miles for GFC vehicles. Each vehicle type had a relatively high standard deviation, ranging from ± 28 to 119 man-hours of their respective means. Again, it is believed that subfleet speed and climate impact subfleet repair times. However, numerical data are not available to support or refute the premise.

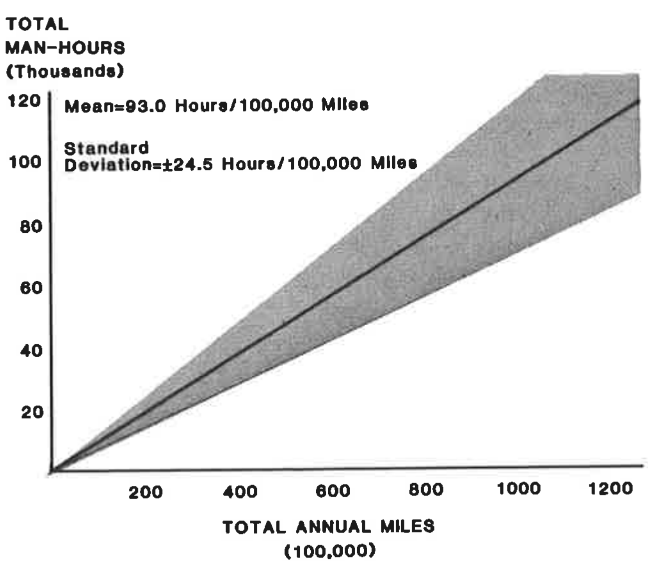


Figure 11. Electrical man-hours.

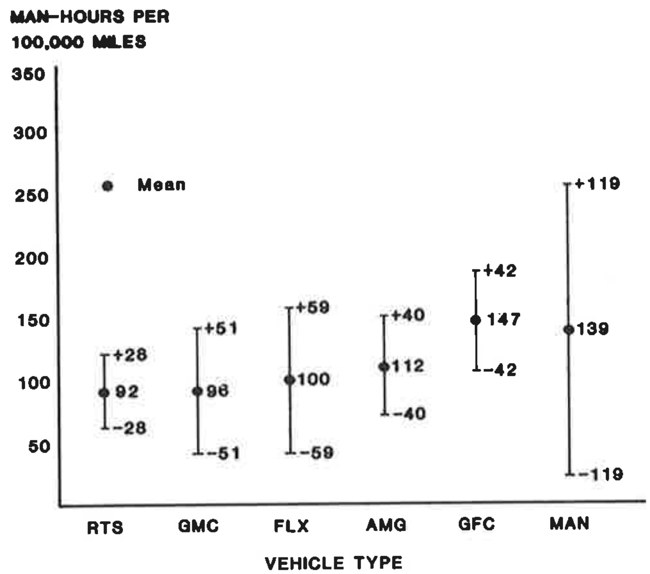


Figure 12. Electrical man-hours by vehicle type.

## 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 different forms. When analyzed independently the results were misleading as data entry was not consistent. The problem of comparability was overcome by combining the three related subsystems into one. The air, steering, and suspension subsystem is comprised of running repair, remove and replace, and rebuild activities for the following:

a. Air compressor.
b. Governor.
c. Air starters.
d. Miscellaneous air components (e.g., door motors, relay valves, applications valves, pressure switches, windshield wiper motors, shutters).
e. Power steering pump.
f. Upper gearbox.
g. Lower gearbox.
h. Air bellows.
i. Radius rods.
j. Sway bars.

Overall, this sybsystem accounts for 5 percent of maintenance man-hours, ranging from 3,200 to 90,000 hours per year in the survey group. The primary independent variable accounting for 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 deviation not accounted for by miles of operation. Correlation analysis was also conducted using average speed and climate as independent variables, with no significant relationship found. Steering and suspension repair hours are probably related to road conditions (e.g., potholes), but no numerical data were available to evaluate this factor.

On the average, the survey agencies required 76.5 hours per 10,000 milesto maintain air, steering, and suspension systems, as illustrated in Figure 13. The standard deviation was ± 26.0 hours per 100,000 miles. It is difficult to account for the remaining difference, as road condition data were not collected under this research effort.

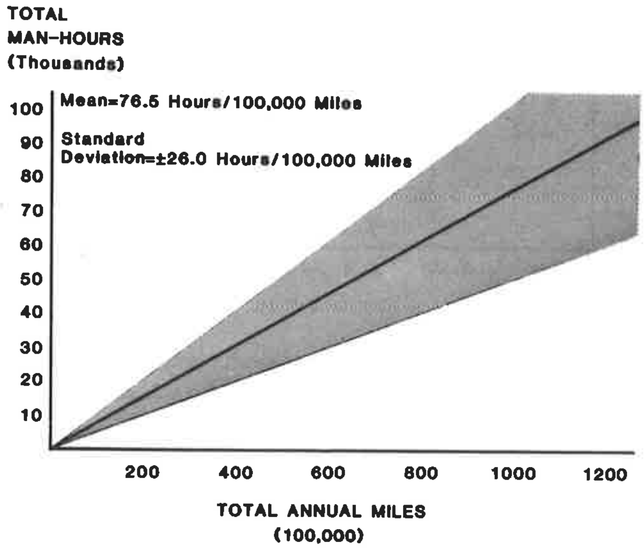


Figure 13. Air, steering, and suspension man-hours.

## 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 by combining the areas. The air conditioning, heating, and ventilation subsystem is comprised of running repair, remove and replace, and rebuild work on the following components:

a. Compressor.
b. Alternator.
c. Condensor.
d. Miscellaneous air conditioning components.
e. Blower motors.
f. Heater core.

Overall, this subsystem accounted for 5 percent of total maintenance man-hours, ranging from a low of 1,500 hours to a high of 69,000 hours 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 0.87. 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 properties have policy mandates to keep all air conditioners functioning, while others will accept some failures.

The mean and standard deviation for hot and humid summers is 168.5 and ± 52.0 man-hours per 100,000 miles, respectively (Figure 14). Hot and dry climates reported a mean of 83.5 hours per 100,000 miles and a standard deviation of ± 27 man-hoursper 100,000 miles. Agencies with a cool and mild summer (i.e., those which generally operate without air conditioning) reported a mean of 27.0 hours per 100,000 miles and a standard deviation of ± 17.0 hours. The side deviation here is chiefly attributable to the winter climate, which ranges from mild in the northwestern United States to severe in the Rocky Mountains.

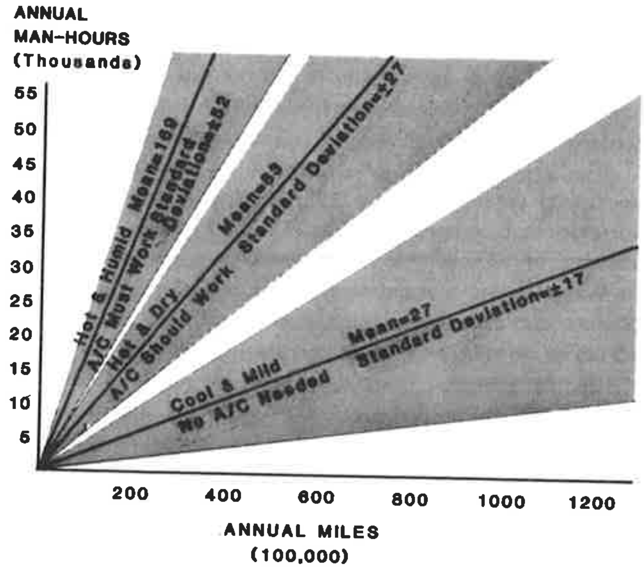


Figure 14. Air conditioning and heating man-hours.

## Drivetrain

The drivetrain subsystem is comprised of running repair, remove and replace, and rebuild work on the transmission and differential. Tear down, cleaning and rebuild of small accessories is also included here. Overall, the drivetrain subsystem accounts for 5 percent of total maintenance man-hours, and ranges from 1,100 hours to 88,600 hours 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 0.77. An additional 0.14 is added by examining transmission type, bringing the total correlation up to 0.91, leaving 9 percent of the variation in man-hours not accounted for. Average speed on the systemwide level added 0.06 to the aggregate, but was not available on the subfleet level, and therefore was omitted.

On the average, the survey properties reported 73 man-hours per 100,000 miles for drivetrain maintenance as shown in Figure 15. The standard deviation was ± 17 hours, mostly a function of the type of transmission accumulating miles. As depicted in Figure 16, mean drivetrain labor-hour requirements ranged from an average of 58 hours per 100,000 miles for the V730 to an average of 139 hours per 100,000 miles for the Renk Dormat 874A. The VH and VS

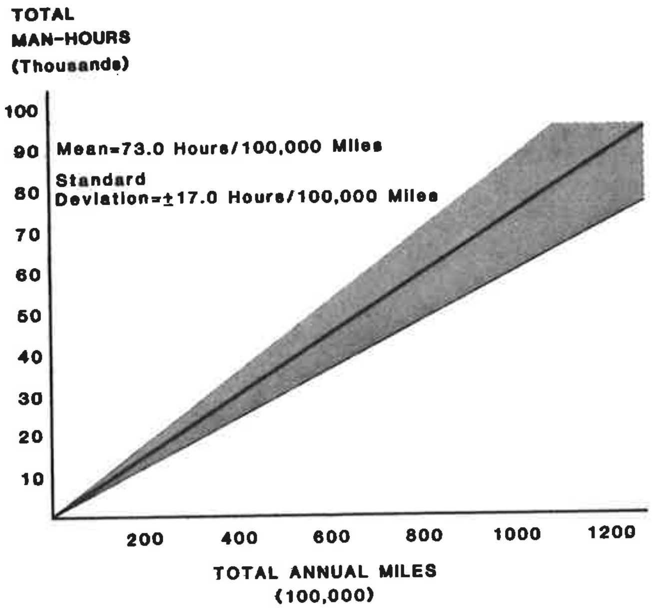


Figure 15. Drivetrain man-hours.

transmissions were grouped together in the manpower reporting. The mean repair time per 100,000 miles for these transmissions was reported at 135 hours.

The deviation of man-hours by transmission type is believed to be a function of line speed. While speed numbers are not available by subfleet, there was a correlation at the systemwide level. Additionally, two operators running Renk's exclusively in slow speed service were at the upper end of manpower requirements. Conversely, the two operators running Renk's exclusively in high speed service were on the lowest end of the man-hour requirements.

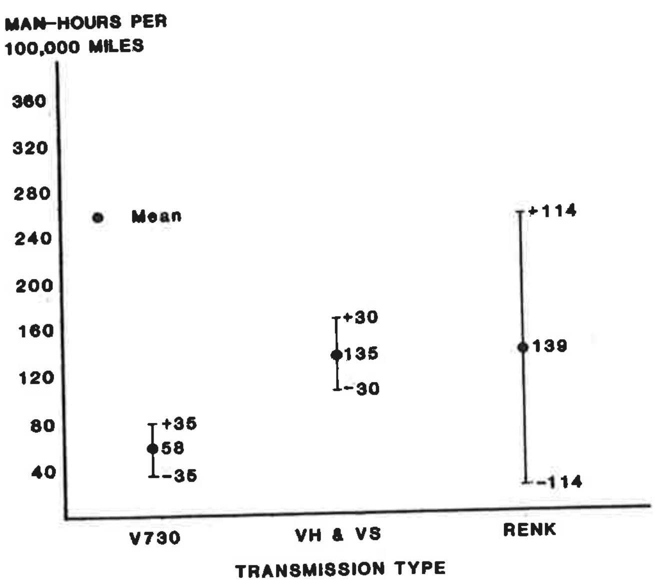


Figure 16. Drivetrain man-hours by transmission type.

## Accessories

The accessories subsystem is comprised of four major components and miscellaneous repairs:

a. Farebox.
b. Destination sign.
c. Radio.
d. Wheelchair lift.

Each of these components was analyzed separately because properties varied substantially in regards to contracting policies and components used. Overall, accessories accounted for 5 percent of total maintenance man-hours. The primary factor determining man-hours requirements is the number of active vehicles equipped with the component.

The coefficient of correlation between total accessories repair hours and active vehicles is 0.62. The standard error of 38 percent results because different properties have different accessories and policies regarding acceptable failure levels.

Mechanical fareboxes required a mean of 11.0 hours per year per active vehicle, with a standard deviation of ± 7.2 hours for repair, as shown in Figure 17. Only two properties operated electronic fareboxes, and were excluded for lack of data points. Two types of destination signs were used: curtain and electrical (dot matrix). The curtain signs averaged 7.3 hours per year per vehicle, and electrical signs averaged 6.0 hours per year. Wheelchair lift repair exhibited the greatest deviation, with a mean of 14.7 hours per year and standard deviation of ± 19.3 hours. Several properties were equipped with lifts on every bus and were required to keep them functional at all times. Other properties found some failure rate acceptable, and this required fewer maintenance hours.

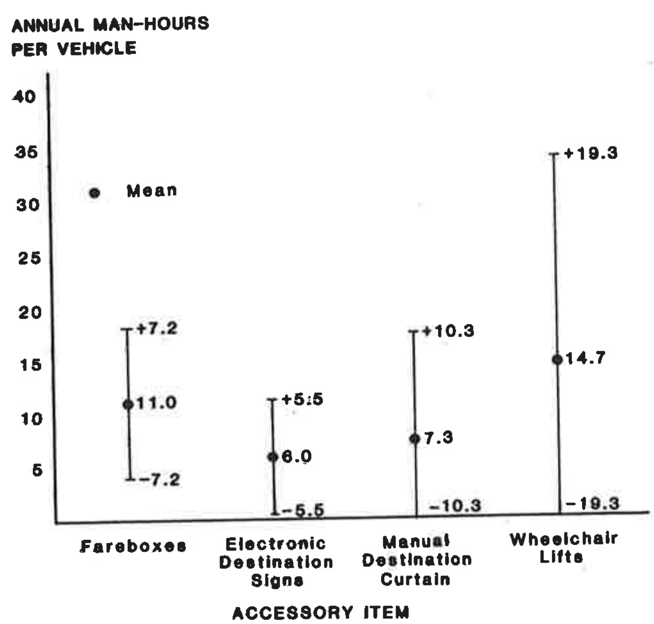


Figure 17. Accessory man-hours.

## Cooling

The cooling function is comprised of all maintenance activities on the following components:

a. Fan torus.
b. Radiator.
c. Surge tank.
d. Water pump.
e. Shutters.
f. Hoses and piping.
g. Other miscellaneous repairs.

Overall, the cooling subsystem accounts for 3 percent of total manpower and ranges from 300 to 45,900 hours per year in the survey agencies. The primary cause of the deviation is miles of operation, with summer climate also having a significant impact.

The coefficient of correlation between the independent variables of vehicle-miles and climate to cooling man-hours is about 0.75. 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 hours per 100,000 miles. The properties with moderate summer temperatures reported substantially lower man-hour needs with a mean of 37 hours per 100,000 miles and a standard deviation of ± 12 hours.

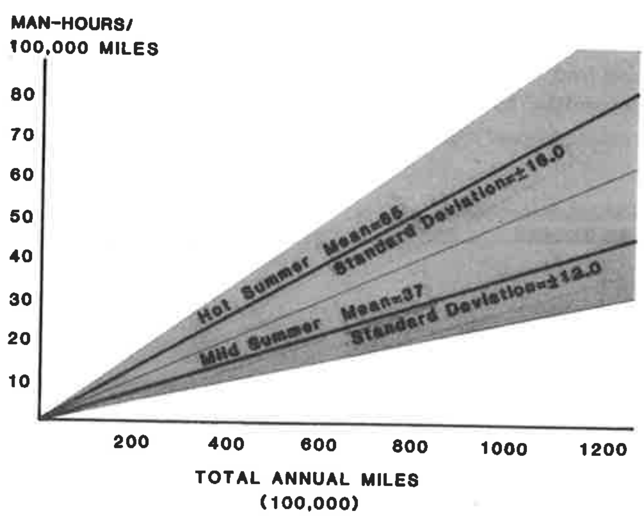


Figure 18. Cooling man-hours by climate.

## Wheels and Tires

Wheels and tires include all maintenance man-hours devoted to this subsystem. It is important to note that many agencies contract for this work, and little or none is done in-house. Of the 15 agencies in the sample size, 7 do no work on tires in house. The remaining 8 vary in the amount of work done in house. Some only remove and replace tires, while others repair all failures occurring in the swing and night shifts, and the contractor repairs those which can wait until day shift. Overall, wheels and tires accounted for only 1 percent of total maintenance man-hours.

The coefficient of correlation between wheels and tires man-hours and vehicle-miles is 0.57, with a 43 percent standard error. Although the error is substantial, it is primarily a function of different contracting arrangements and is not easily quantified.

On the average, agencies engaged in some wheel and tire repair activites reported 48.6 man-hours per 100,000 miles as illustrated in Figure 19. The standarad deviation was ± 21.0 hours. Again, the difference is primarily attributable to contracting and hence work differences.

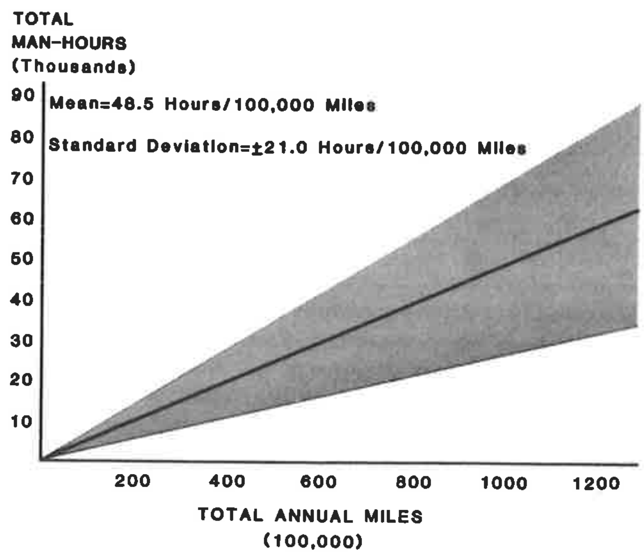


Figure 19. Wheels and tires man-hours.

## Unavailable Time At Work

In addition to work-hours, all transit agencies pay labor for some amount of time not spent on maintaining vehicles. Paid coffee breaks, clean-up time, and paid lunch breaks comprise 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 maintenance staff is unavailable for work per day by 0.0025 and adding one (1), as shown in Figure 20. In the survey group, agencies reported an average of 45 minutes per day in unavailable time. This translates to an expansion factor of 1.103. The highest unavailable time was 90 minutes per day, which requires an expansion factor of 1.231. The lowest unavailable time was 30 minutes, 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.

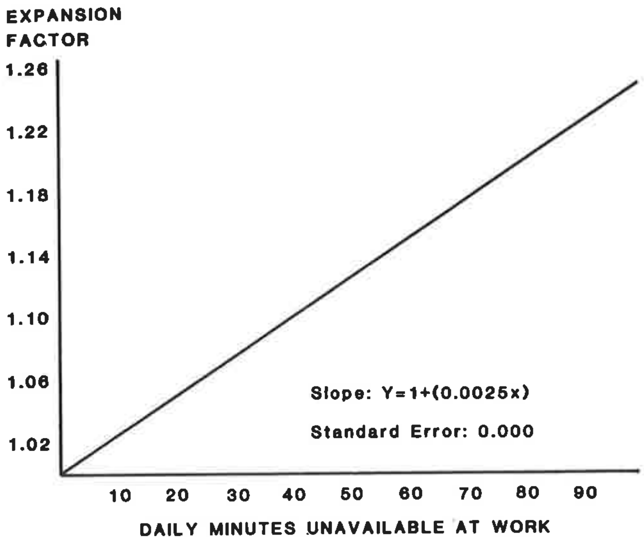


Figure 20. Unavailable time at work.

The expansion factor can be estimated by multiplying unavailable days by 0.0052 and adding one (1), as shown in Figure 21. On the average, properties 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, the use of overtime reduces the manpower requirement in terms of bodies, as 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 translating hours into staffing levels.

The overtime compression factor can be estimated by subtracting the proportion of total work-hours conducted at overtime from one (1), as illustrated in Figure 22. The compression factor is then multiplied by expanded hours to produce staff hours. On the average, survey properties reported 5.8 percent of hours were worked at overtime. The range of overtime was large, ranging from 0.2 percent to 19.2 percent.

## Supervision

Supervision was evaluated as a function of line staffing levels separately for cleaning and servicing and mechanic staffs. It is generally believed that mechanic training/skill levels also impact supervisory requirements. The research

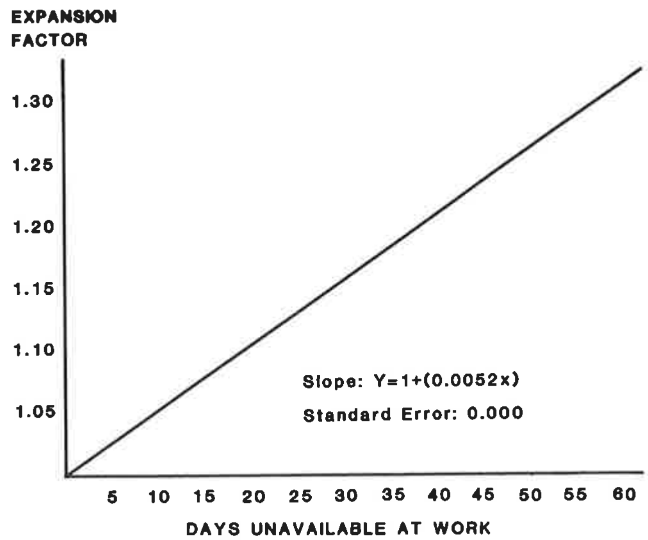


Figure 21. Time not at work.

team was unable to analyze this potential impact because mechanic ranks and skills definition was not consistent or quantifiable among the survey agencies.

Overall, transit agencies required a lower level of supervision (e.g., more line staff members per supervisor) for cleaning and servicing than for mechanic staffs. The mean supervisor-to-staff ratio for cleaning and servicing was 1:8, as illustrated in Figure 23. The standard deviation ranged from 1:5 to 1:35. The mean supervisor-to-mechanic ratio was 1:6, with a standard deviation ranging from 1:4 to 1:14.

It is difficult to evaluate supervisory requirements based on the experience of other agencies, because each agency may have unique work provisions, supervisory duties, and management needs. For example, many agencies had working supervisors who made repairs and cleaned buses. Other agencies used supervisors for training, quality control, and work scheduling exclusively. Frequently, the same supervisor would have responsibility for servicer and mechanic activities. In some instances, transit agencies supplemented supervisory staff with senior mechanics who served in a supervisory role on weekends and graveyard shifts.

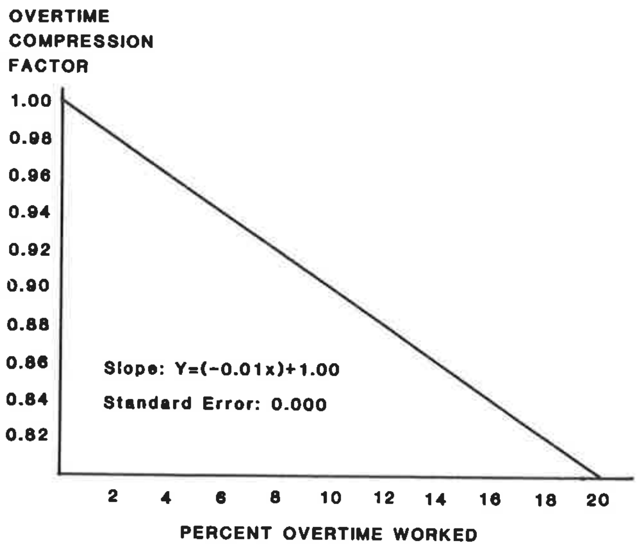


Figure 22. Overtime factor.

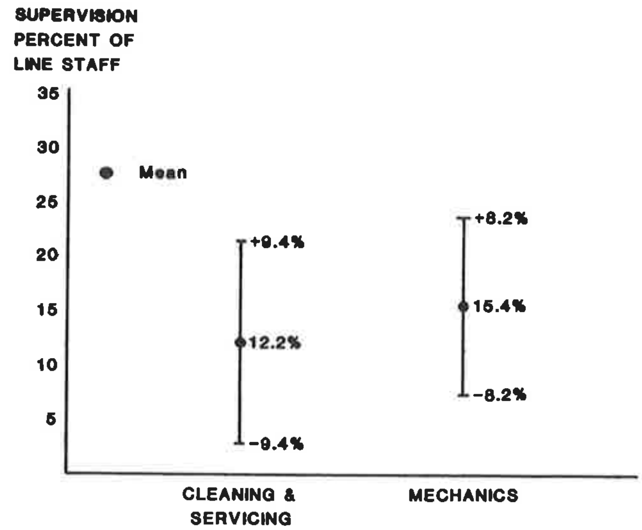


Figure 23. Supervision as percent of line staff.

CHAPTER THREE

# INTERPRETATION, APPRAISAL, APPLICATION

## FUNCTIONAL MANPOWER PLANNING MODEL

The research team utilized a rigorous manpower planning technique to investigate the factors influencing maintenance manpower requirements. The investigative technique was based on task times and frequencies by functional area, vehicle subsystem and subsystem components for each individual subfleet for each agency, as described in Chapter One. The manpower analysis required application of more than 110 calculations per subfleet per agency to determine maintenance labor needs. The survey agencies participating in the research effort had between 3 and 11 subfleets each. This translates to between 330 and 1,210 independent calculations per agency, exclusive of summations. While this level of effort was appropriate for the research, it is probably not acceptable for routine planning activities where resources and time are constrained.

The findings of the study, presented in Chapter Two, indicate that maintenance staffing can be estimated with a high level of accuracy at a greater level of aggregation. The high correlation between independent variables and man-hours, and the relatively narrow standard deviations support the case for estimating manpower on a functional level. In addition to providing sound results, the level of effort needed to apply the model and analyze manpower levels is reduced enormously.

This chapter presents both graphical solutions, in the form of nomographs, and numeric equations for estimating manpower requirements based on local operating characteristics. A nomograph is a chart containing scales for the variables in the mathematical equation, their relative magnitudes and relative positions being such that corresonding values of the variables are found at the points on the scales which are intersected by the same straight line. The nomographs provide a quick and easy method for evaluating labor requirements using a straight edge to identify operating parameters and corresponding man-hour requirements. The nomographs result in some loss of precision as a result of scale limitations and visual interpolation of intermediate values between defined points of the graph. Even so, the nomograph does provide a sound estimate of manpower and affords a simplistic means for evaluating current labor utilization against other industry experience.

Numeric algorithms are provided as well, thus providing the manpower analyst with the option of calculating maintenance manpower requirements directly. In this case, a greater degree of precision can be attained with some additional effort required.

Whether using the functional model to analyze existing labor utilization as compared to other agencies, or to estimate local staffing requirements, the model should be used with discretion. When comparing estimated versus actual manpower levels at the vehicle subsystem level, one should make sure that activities and tasks are consistent. A detailed description of subsystem components and activities is presented in Chapters One and Two to facilitate this evaluation. Also, if a substantial difference exists between the estimated and actual man-hours used, one should investigate the reasons for the discrepancy. In some cases a unique local characteristic may justify the difference, and in others there may be an opportunity for improved labor utilization.

**Servicing and Cleaning**

The servicing and cleaning function is generally characterized by a dedicated staff of servicers who perform daily servicing, major interior cleaning and chassis wash on a regular basis. The man-hour requirements are chiefly a function of the number of peak vehicles operated. Knowing the daily peak vehicle requirement, labor-hours can be determined using the cleaning and servicing nomograph depicted in Figure 24. The nomograph is used by aligning a straight edge with the appropriate number of peak vehicles (left scale) and passing the line through the focal point (lying in the center of the graph). The point at which the line intersects the man-hours scale (right scale) determines the annual labor-hour requirement.

Servicing man-hour needs can also be determined by applying the following Eq. 16.

$$\text{Servicing Hours} = \text{Peak Vehicles} * 138.5 \text{ Hours/Vehicle} \quad (16)$$

It is important to note that the analysis identified a standard error of about 13 percent around the mean hours provided above. The reasons for the variance include differences in facility layout, which impact vehicle movement efficiency, and the frequency of major interior cleans. Most of the survey properties had a major clean cycle on a monthly basis, fewer or more frequent cleanings would have a like impact on total man-hours.

**Inspections**

The inspection function is generally comprised of a number of scheduled inspection activities and preventive maintenance tasks. The primary factor influencing inspection hours is maintenance philosophy. When compared to annual vehicle-miles, inspection man-hours averaged 239.6 hours per 100,000 miles. However, the standard deviation was 80 percent around the mean. Because of the wide variation between maintenance organizations with regard to inspection policy, man-hours for this function should be estimated based on each property's specific preventive maintenance program. The calculation methodology is shown in Eq. 17.

$$\sum_i \sum_j \text{Inspection Time Spent on Repair} * \left( \text{Annual Miles}_j \Big/ \text{Miles Between Inspections}_{ij} \right) \quad (17)$$

Where:
i = Inspection type
j = Vehicle type

Inspection types may include safety, minor, major, and statutory inspections. If some time for repair is normally included in the inspection program, it should be included in the "hours to perform" number.

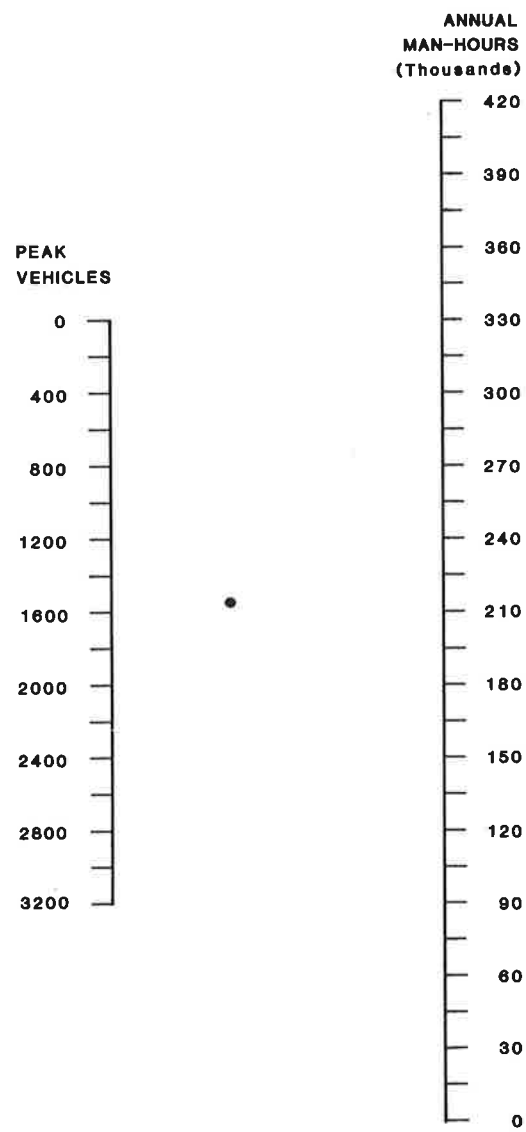


Figure 24. Graphic solution to cleaning and servicing man-hours.

## Body

The body subsystem is comprised of running repair and major repair to body, painting, upholstery and glass. Body man-hours are a function of both vehicle-miles and the accident rate. The annual man-hours for this activity area can be estimated using the nomograph presented in Figure 25. Using a straight edge, one should draw a line through the appropriate mileage intercept (left scale) and the appropriate accident rate (center scale). The intercept on the right scale is the corresponding hours requirement for body work.

Body man-hours can be estimated mathematically using Eq. 18 as follows:

$$\text{Body Hours} = \text{Miles}/100{,}000 \ * \ (5.5 \text{ Hours} \ * \ \text{Accidents Per Million Miles}) \quad (18)$$

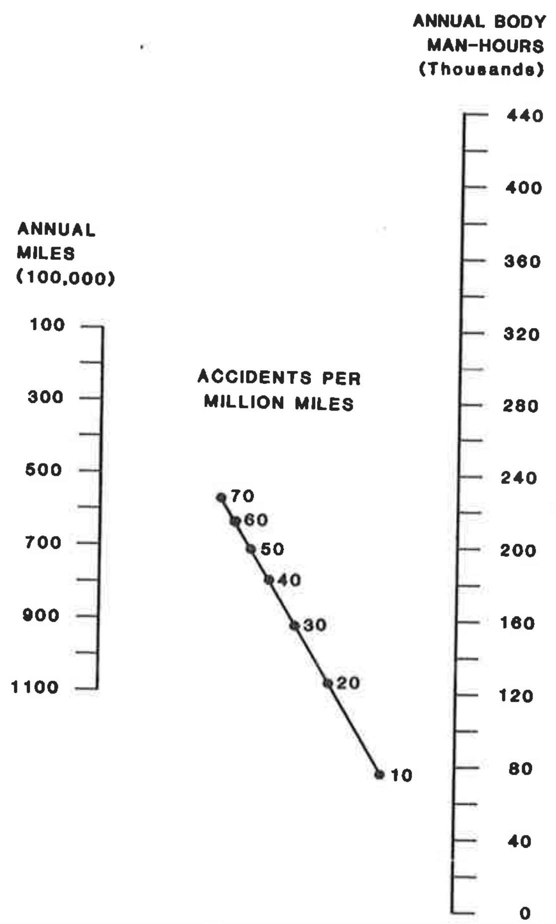


Figure 25. Graphic solution to body man-hours.

On the average, the survey properties had 40 accidents per million miles, or 220 man-hours per 100,000 bus miles. The standard deviation was ± 19.5 man-hours (i.e., 9 percent of the mean), due primarily to policy on the acceptable appearance of vehicles (e.g., painting frequency).

## Engine/Fuel

The engine and fuel subsystem includes all repair, remove and replace, and rebuild times involved in maintaining these subsystems and their components. Engine and fuel man-hour requirements vary in relation to vehicle-miles of operation and vehicle type (e.g., manufacturer). The annual labor-hour requirement for this activity area can be estimated using the nomograph shown in Figure 26. To use the nomograph, draw a straight line from the amount of annual miles accumulated by a particular subfleet through the focal point representing that subfleet. The intercept on the right scale is the man-hour requirement. Total annual man-hours are found by summing the subfleet amounts. If the fleet mix or subfleet mileage is unknown (or not represented on the chart), one should draw the line through the focal point representing FLX and RTS, because they are equivalent to the average of all fleet types in the study.

Labor requirements can be estimated for the entire fleet by Eq. 19 as follows:

$$\text{Engine/Fuel Hours} = \text{Miles} \ * \ 157 \text{ Hours}/100{,}000 \text{ Miles} \quad (19)$$

At the fleetwide level, there is a standard deviation of ± 38 hours per 100,000 vehicle-miles. If greater accuracy is desired, the analysis should be conducted at the subfleet level using Eq. 20.

$$\text{Engine/Fuel Hours} = \sum_i \text{Miles}_i \ * \ \text{Hours}_i/100{,}000 \text{ Miles} \quad (20)$$

Where:

i = Fleet type (e.g., manufacturer)

The "hours per 100,000 miles" value for several subfleets is as follows:

a. GMC= 130 hours, ± 46 hours standard deviation.
b. FLX = 155 hours, ± 51 hours standard deviation.
c. RTS = 156 hours, ± 48 hours standard deviation.
d. GFC = 166 hours, ± 10 hours standard deviation.
e. AMG= 181 hours, ± 84 hours standard deviation.
f. MAN= 229 hours, ±136 hours standard deviation.

It is believed that subfleet linespeed, vehicle age, mechanic training, equipment, and facilities all impact vehicle times to some degree.

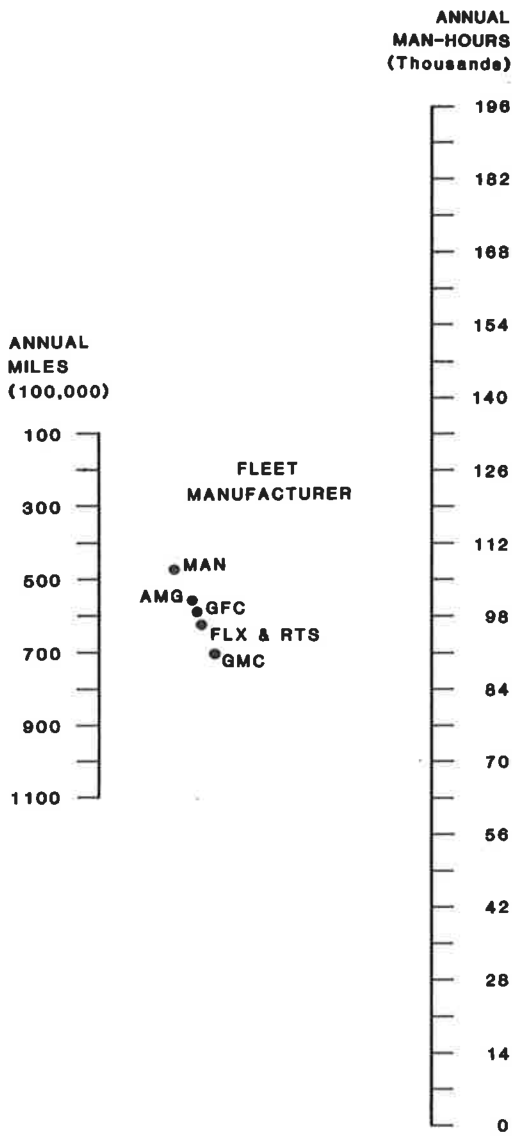


Figure 26. Graphic solution to engine and fuel man-hours.

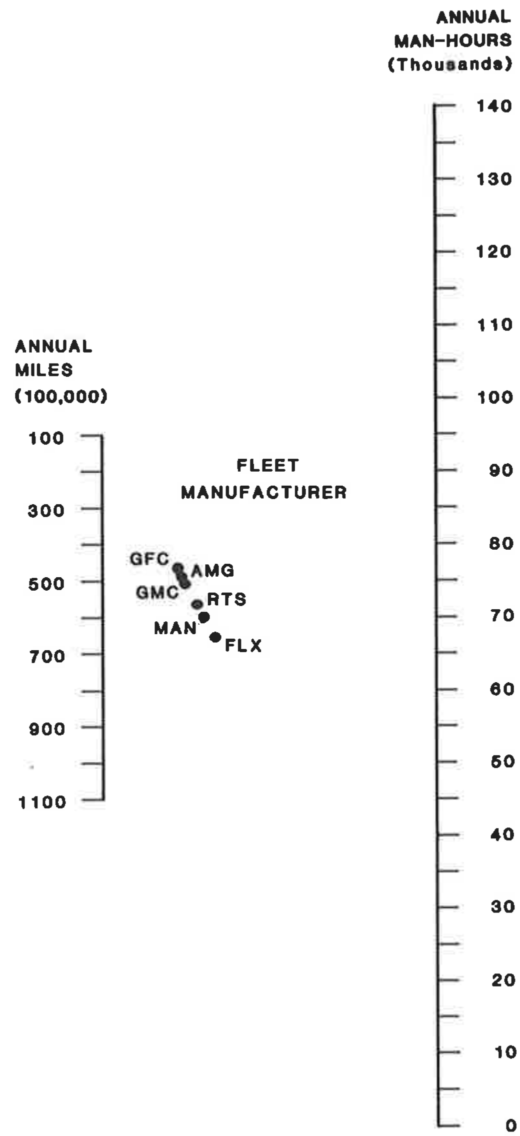


Figure 27. Graphic solution to braking man-hours.

## Braking

The braking subsystem is comprised of all running repair and reline work required to maintain bus brakes. Labor requirements in this activity area are a function of miles of operation and fleet type (e.g., manufacturer). Annual labor requirements can be estimated using the nomograph illustrated in Figure 27. Using a straight edge, one should draw a line from the appropriate subfleet mileage through the corresponding subfleet focal point. The intercept on the right scale is the annual man-hour requirement. Total annual man-hours are found by summing subfleet amounts. If subfleet mileage is unknown or one of the subfleets is not listed, use the fleetwide mileage and the RTS focal point (RTS repair requirements are equivalent to the study average for all fleets).

Annual braking labor-hours can also be estimated at the fleetwide level by Eq. 21.

$$\text{Braking Hours} = \text{Miles} * 123.5 \text{ Hours}/100{,}000 \text{ Miles} \qquad (21)$$

This measure resulted in a ± 31 hours per 100,000 miles standard deviation. If greater accuracy is desired, the calculation, using Eq. 22., can be made by subfleet as follows:

$$\text{Braking Hours} = \sum_i \text{Miles}_i * \text{Hours}_i/100{,}000 \text{ Miles} \quad (22)$$

Where:
i = Fleet type (e.g., manufacturer)

The "hours per 100,000 miles" value for several subfleets is as follows:

a. FLX = 102 hours, ± 61 hours standard deviation.
b. RTS = 125 hours, ± 23 hours standard deviation.
c. GMC = 147 hours, ± 58 hours standard deviation.
d. AMG = 152 hours, ± 55 hours standard deviation.
e. GFC = 158 hours, ± 68 hours standard deviation.
f. MAN = 116 hours, ± 80 hours standard deviation.

Vehicle speed, terrain, and mechanic skill levels all are believed to contribute to the remaining deviation.

### Electrical

The electrical subsystem is comprised of running repair, remove and replace, and rebuild activities for starters, alternators/generators, batteries and miscellaneous electrical components. Electrical man-hours are a function of vehicle-miles and fleet type (e.g., manufacturer). The annual labor-hour requirement for maintaining this subsystem can be estimated using the nomograph depicted on Figure 28. Using a straight edge, one should draw a line from the appropriate subfleet mileage point (left scale) through the corresponding focal point. The electrical man-hour requirement for that fleet is the value of the intercept on the right scale. Total annual man-hours are found by summing the subfleet amounts. If subfleet mileage is unknown, or a subfleet is not represented in the graph, use the GMC focal point because it is equivalent to the average of all fleet types reviewed.

Total annual electrical hours can be estimated at the fleetwide level by Eq. 23 as follows:

$$\text{Electrical Hours} = \text{Miles} * 93 \text{ Hours}/100{,}000 \text{ Miles} \quad (23)$$

The standard deviation at the fleetwide level is ± 24 hours per 100,000 miles. If greater accuracy is desired, the calculation can be done by subfleet, using Eq. 24 as follows:

$$\text{Electrical Hours} = \sum_i \text{Miles}_i * \text{Hours}_i/100{,}000 \text{ Miles} \quad (24)$$

Where:
i = Fleet type (e.g., manufacturer)

The values for "hours per 100,000 miles" as determined in this research effort are:

a. RTS = 92 hours, ± 28 hours standard deviation.
b. GMC = 93 hours, ± 51 hours standard deviation.
c. FLX = 101 hours, ± 59 hours standard deviation.
d. AMG = 111 hours, ± 40 hours standard deviation.
e. GFC = 147 hours, ± 42 hours standard deviation.
f. MAN = 139 hours, ± 119 hours standard deviation.

Again, it is believed that subfleet speed and age impact electrical repair times as well. However, no numeric data were available to support this premise.

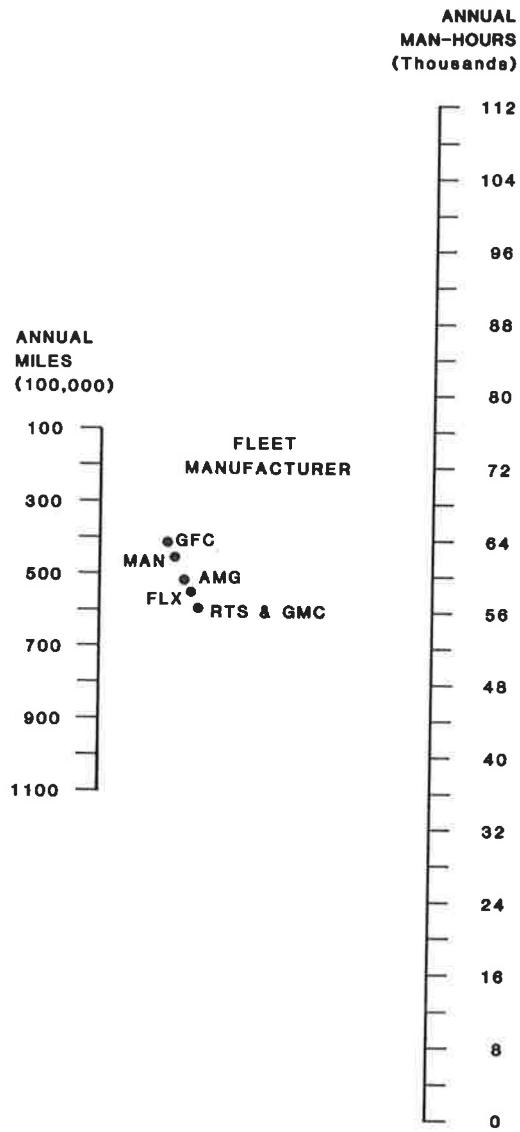


Figure 28. Graphic solution to electrical man-hours.

### Air, Steering, and Suspension

The air, steering, and suspension subsystem is comprised of all maintenance activities devoted to these areas. Man-hours in this subsystem vary as a function of fleet-miles of operation. Annual labor-hours can be estimated with the nomograph depicted in Figure 29. Using a straight edge, one should align the annual miles coordinate with the focal point. The intercept on the right scale depicts annual man-hours for air, steering, and suspension.

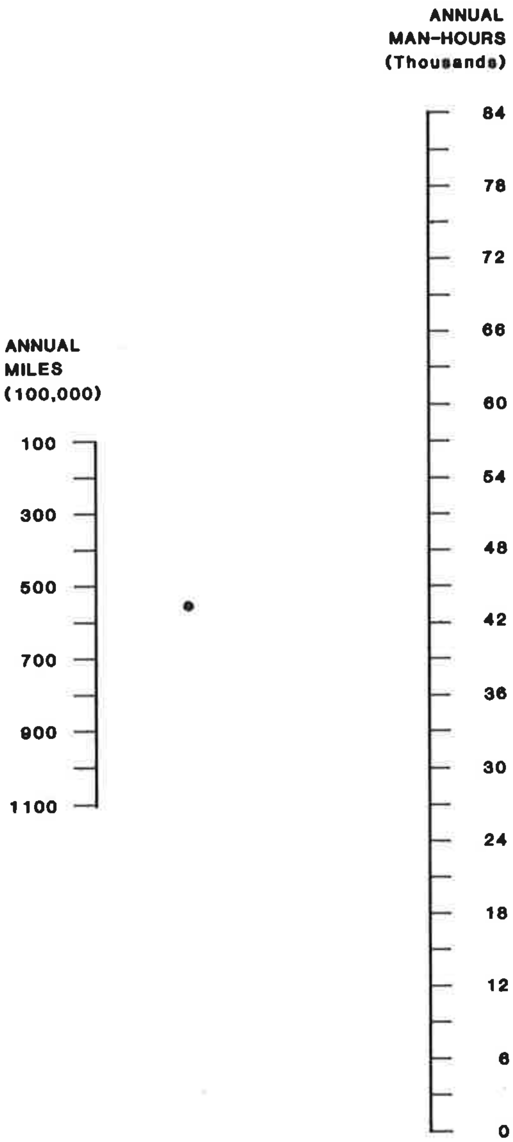


Figure 29. Graphic solution to air, steering and suspension man-hours.

Labor-hours can also be estimated by Eq. 25 as follows:

$$\text{Air Hours} = \text{Miles} * 76.5\ \text{Hours}/100{,}000\ \text{Miles} \quad (25)$$

The standard deviation in the survey group was ± 26 hours per 100,000 miles. It is believed that roadway conditions may account for most of the deviation (e.g., rough roads require more hours), although no numeric data were available to confirm or refute the premise.

**Air Conditioning and Heating**

The air conditioning, heating, and ventilation subsystem comprised of all repair, remove and replace, and rebuild activities in this area. Annual man-hours are a function of miles operated and climatic conditions. Only summer climate had a significant impact, ranging from hot and humid (air conditioning must work) to cool and mild (no air conditioning needed). The labor requirement can be estimated with the nomograph presented in Figure 30. Using a straight edge, one should draw a line from the appropriate mileage intercept on the left scale through the corresponding focal point depicting relative summer climate. The intercept on the right scale defines annual man-hours.

Air conditioning and heating man-hours can be estimated by algorithm (Eq. 26) as well:

$$\text{A/C \& Heating Hours} = \text{Miles} * \text{Hours}_c/100{,}000\ \text{Miles} \quad (26)$$

Where:
c = Summer climate

The "hours per 100,000 miles" value for the three types of summer climate is as follows:

a. Hot and Humid = 168.5, ± 52 hours standard deviation.
b. Hot and Dry = 83.5, ± 27 hours standard deviation.
c. Cool and Mild = 27.0, ± 17 hours standard deviation.

The remaining variation is primarily due to subclimate differences and policy on heating and air conditioning availability.

**Drivetrain**

The drivetrain system is comprised of running repair, remove and replace, and rebuild work on the transmission and differential. Drivetrain labor requirements are a function of vehicle-miles and the type of transmissions accumulating miles. Man-hours can be estimated with the nomograph depicted on Figure 31. Using a straight edge, one should draw a line from the appropriate mileage for a particular transmission type through the corresponding focal point. The sum of each transmission type yields total drivetrain man-hours. If transmission mileage is not known, draw the line midway between the VH and VS focal point and the V730 focal point. This value represents the mean labor-hour requirement for all transmission types.

Drivetrain man-hours can also be calculated by algorithm (Eq. 27) for fleetwide needs as follows:

$$\text{Drivetrain Hours} = \text{Miles} * 73\ \text{Hours}/100{,}000\ \text{Miles} \quad (27)$$

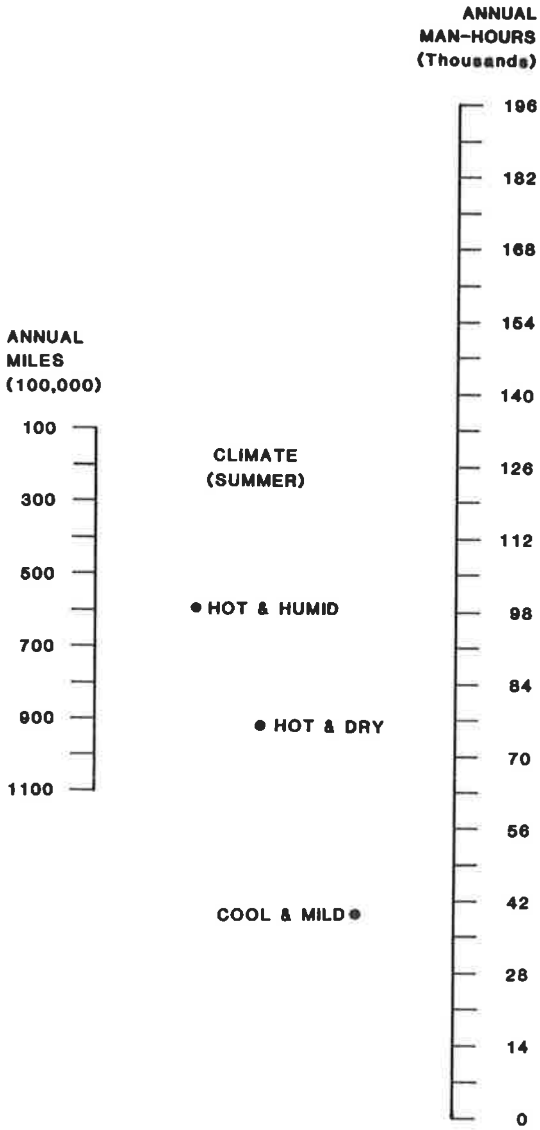


Figure 30. Graphic solution to air conditioning and heating man-hours.

At the fleetwide level, this value has a standard deviation of ± 17 hours per 100,000 miles. If greater accuracy is desired, the calculation can be made by transmission type, using Eq. 28:

$$\text{Annual Hours} = \sum_{d} \text{Miles}_d * \text{Hours}_d/100{,}000 \text{ Miles} \quad (28)$$

Where:
d = Transmission type

The values for the transmissions included in the research are:

a. V730 = 58 hours, ± 35 hours standard deviation.
b. VH & VS = 135 hours, ± 30 hours standard deviation.
c. Renk Dormat 874A = 139 hours, ± 114 hours standard deviation.

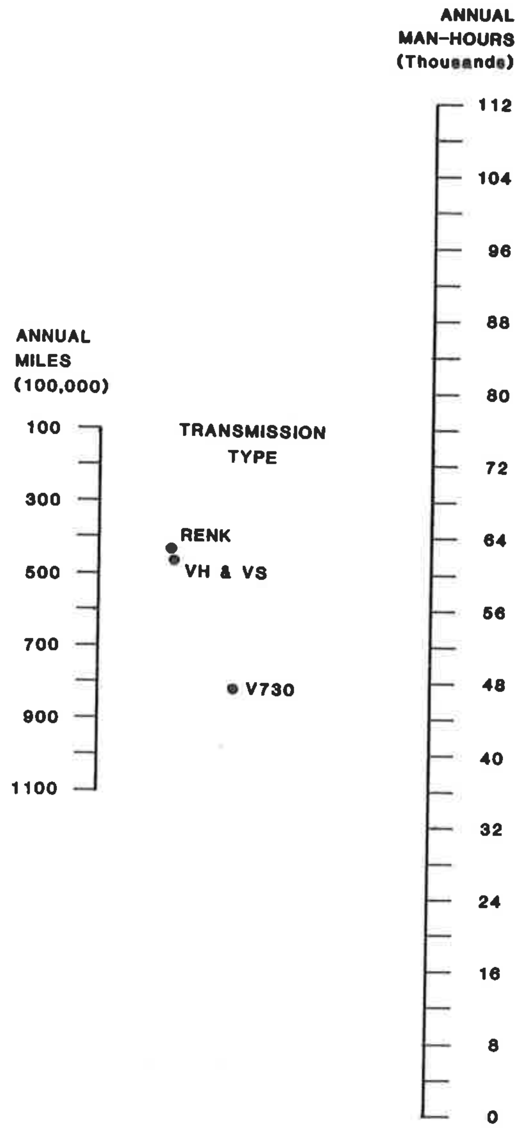


Figure 31. Graphic solution to drivetrain man-hours.

The remaining variation is believed to be a function of speed, although subfleet speed was unavailable to confirm or refute this premise.

### Cooling

The cooling subsystem is comprised of all maintenance activities on the engine cooling system. Labor-hour requirements are a function of miles and summer climate (defined as hot or moderate). Man-hours can be estimated with the nomograph illustrated on Figure 32. Using a straight edge, one should draw a line from the appropriate mileage intercept through the corresponding focal point (i.e., hot or moderate summer). The intercept on the right scale defines labor-hour needs.

Cooling system repair hours can be estimated by Eq. 29, as follows:

$$\text{Cooling Hours} = \text{Miles} * \text{Hours}_c/100{,}000 \text{ Miles} \quad (29)$$

Where:
c = Summer climate (i.e., hot or moderate)

The calibrated man-hour requirements resulting from the research were:

a. Hot = 65 hours, ± 16 hours standard deviation.
b. Moderate = 37 hours, ± 12 hours standard deviation.

The remaining deviation is believed to be a function of subclimates and line speed, but supporting data were unavailable.

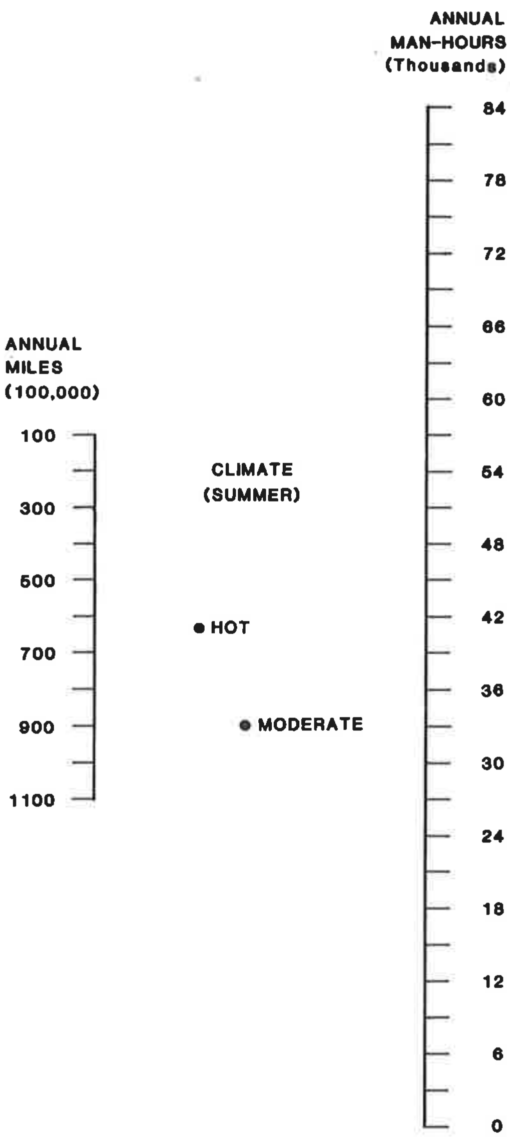


Figure 32. Graphic solution to cooling man-hours.

**Wheels and Tires**

Wheels and tires include all maintenance activities devoted to this subsystem. It is important to note that many properties contract all or part of this work out, and therefore have few or no hours here. For agencies with some wheel and tire maintenance in-house, the nomograph presented in Figure 33 can help in labor-hours estimation.

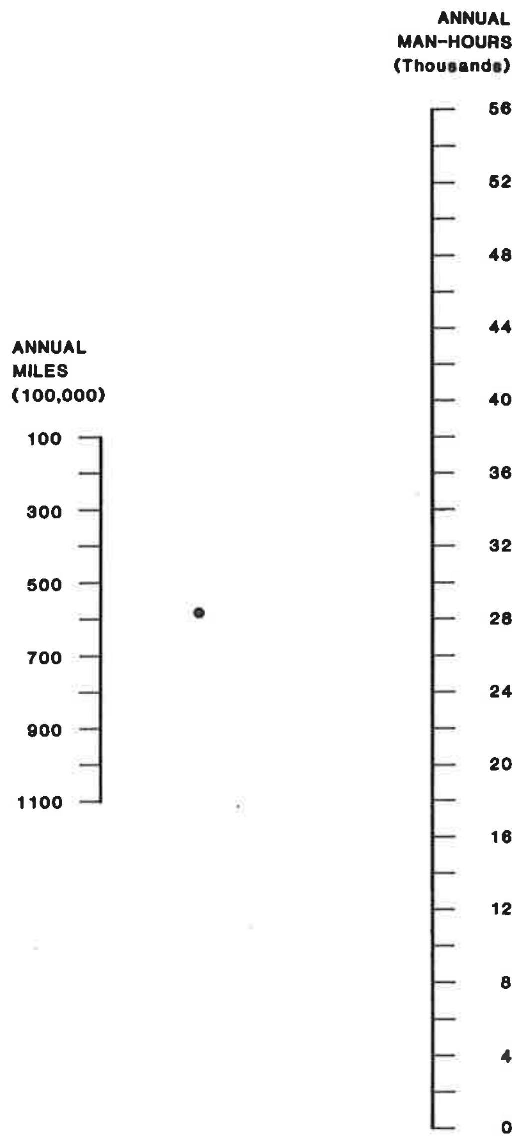


Figure 33. Graphic solution to wheels and tires man-hours.

Using a straight edge, a line should be drawn from the appropriate mileage intercept through the focal point. The intercept on the right scale defines the labor-hour requirement.

Labor-hours for wheels and tires can be estimated by Eq. 30 as follows:

$$\text{Wheels \& Tires Hours} = \text{Miles} * 48.6 \text{ Hours}/100{,}000 \text{ Miles} \quad (30)$$

Because of the wide variation in contracting arrangements in this subsystem, the standard deviation was ± 21 hours per 100,000 miles. An agency that contracts out most work responsibilities would be on the lower end, and one that does most work in-house would be on the upper end.

**Accessories**

The accessories subsystem is comprised of three major activity areas: fareboxes, destination signs, and wheelchair lifts. Labor-hour requirements for each of these areas are a function of peak vehicles. Three nomographs are provided for determining accessory labor-hour requirements (i.e., one for each area). Farebox labor-hours can be determined by drawing a line from the appropriate number of peak vehicles through the focal point in Figure 34. The survey group used only mechanical fareboxes; no data were available on electronic farebox maintenance hours. Destination sign man-hours can be determined separately for buses equipped with manual curtains and electronic dot matrix signs, as shown in Figure 35. Wheelchair lift man-hours are determined by drawing a line from the number of wheelchair equipped buses through the focal point of the nomograph in Figure 36. The sum of these three calculations equals total man-hours for accessories.

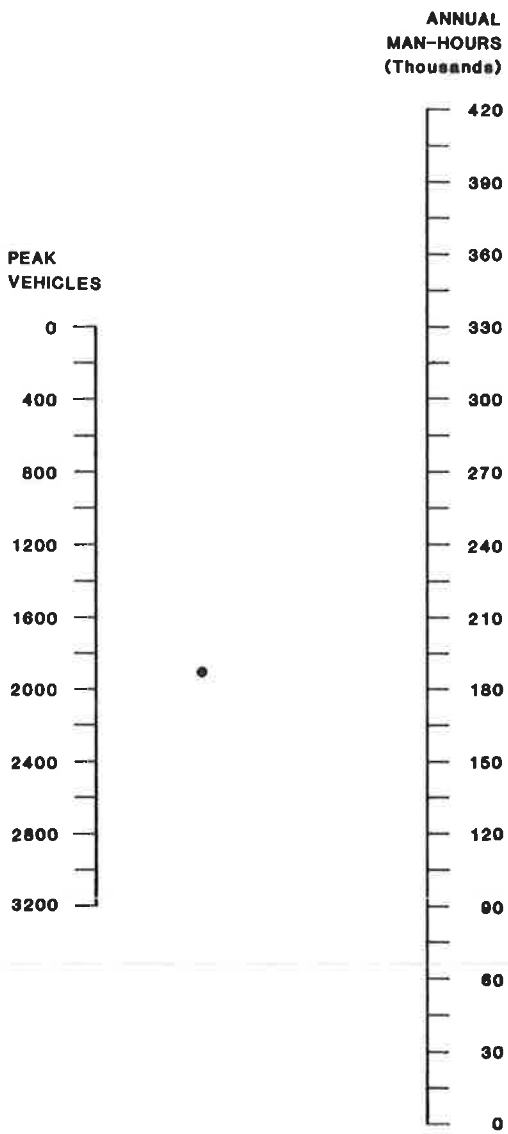


Figure 34. Graphic solution to farebox man-hours.

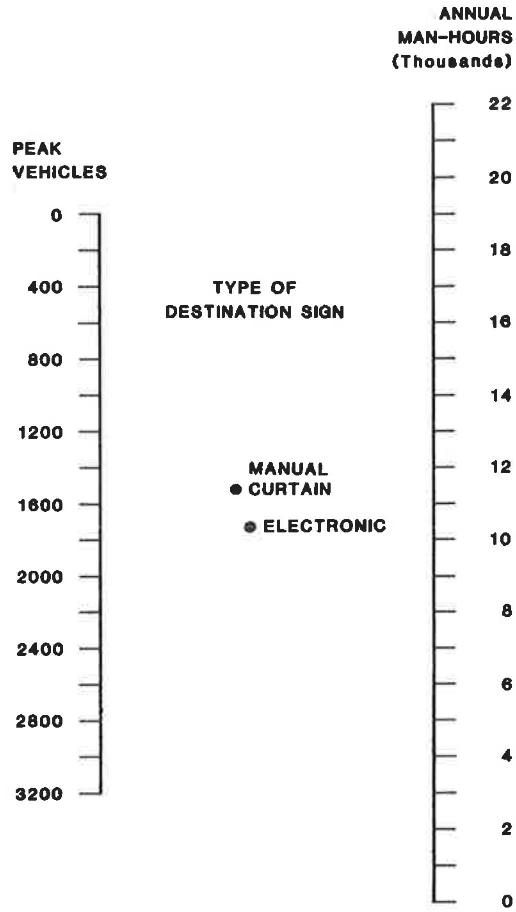


Figure 35. Graphic solution to destination sign man-hours.

Accessory labor requirements can be determined using Eqs. 31, 32, and 33 as follows:

$$\text{Farebox Hours} = \text{Peak Vehicles} * \text{Hours} \quad (31)$$

$$\text{Destination Sign Hours} = \text{Peak Vehicles} * \text{Hours}_a \quad (32)$$

$$\text{Wheelchair Hours} = \text{Peak Vehicles} * \text{Hours} \quad (33)$$

Where:

a = Type of sign (i.e., manual or electronic)

The average hours for repair of accessories, as determined in this research effort, are:

a. Fareboxes = 11.0 hours, ± 7.2 hours standard deviation.
b. Destination Signs (Manual) = 7.3 hours, ± 10.3 hours standard deviation.
c. Destination Signs (Electrical) = 6.0 hours, ± 55 hours standard deviation.
d. Wheelchair Lifts = 14.7 hours, ± 19.3 hours standard deviation.

The high variation in these work areas is chiefly attributable to local policy.

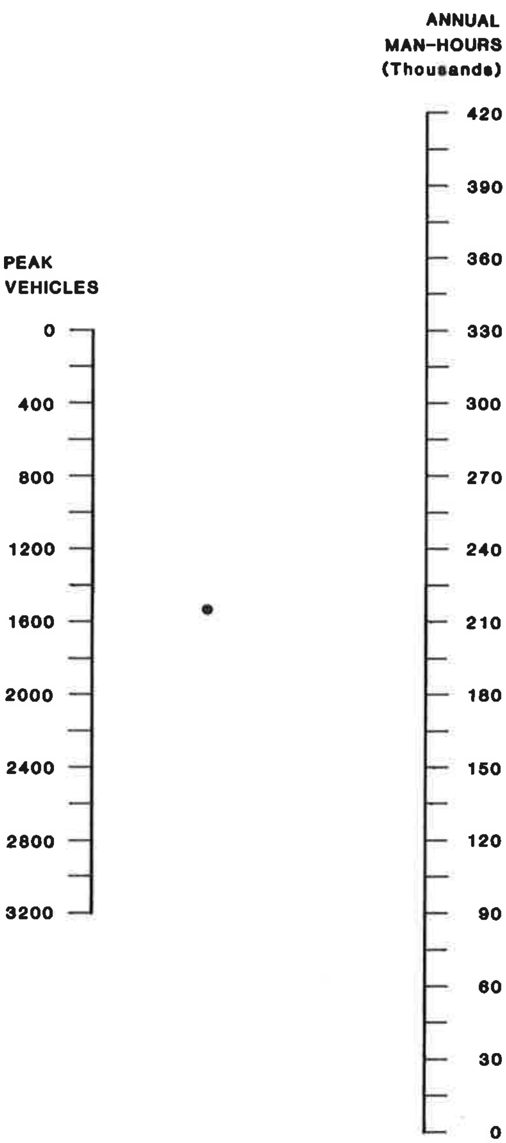


Figure 36. Graphic solution to wheelchair lift man-hours.

## Unavailable Time

Work-hour requirements must be expanded by unavailable time to determine staffing levels. Unavailable time occurs both on the job (i.e., paid breaks, clean-up time) and off the job (e.g., holidays, vacations, absenteeism, excused absences). The expansion factor can be determined with a nomograph, as shown on Figure 37. Using a straight edge, one should draw a line from the daily number of minutes unavailable for work (i.e., break time plus clean-up time) through the total days unavailable per year (assuming a 260 day working year). The intercept on the right scale is the expansion factor.

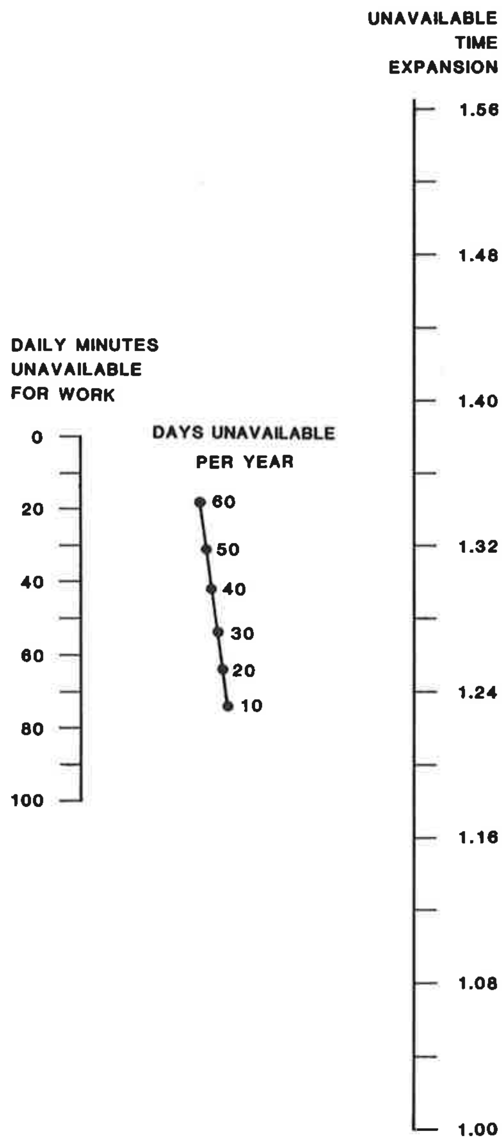


Figure 37. Graphic solution to unavailable time expansion.

The unavailable time expansion factor is determined by Eq. 34, and then carried forward to the overtime analysis.

$$\text{Expansion Factor} = 8 \text{ Hrs}/(8 \text{ Hrs} - \text{Break Hrs}) * 260 \text{ Days}/(260 \text{ Days} - \text{Unavailable Days}) \quad (34)$$

### Overtime

While unavailable time increases the need for manpower, overtime decreases staffing requirements because each person works additional hours. The work-hour adjustment factor can be determined using the nomograph depicted in Figure 38. Using a straight edge, one should draw a line from the appropriate unavailable time expansion factor (calculated in the previous step) through the average overtime percent of total worked hours. The intercept on the right scale is the new adjustment factor.

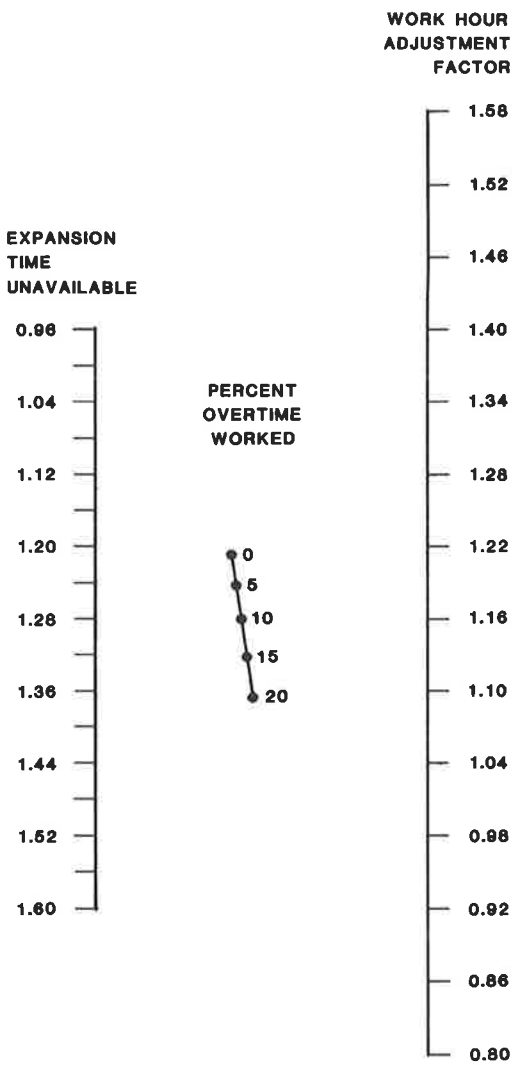


Figure 38. Graphic solution to overtime adjustment.

The adjustment factor can be calculated by Eq. 35 as follows:

$$\text{Adjustment Factor} = \text{Unavailable Expansion Factor} * (1 - \text{Overtime Percent}) \quad (35)$$

The adjustment factor is used to expand work-hours to estimate staffing requirements.

### Staffing Requirements

Staffing requirements can be determined separately for any of the functions in which dedicated staff are applied (e.g., servicing, body), or in aggregate for all maintenance line staff. The calculation is made by summing the work-hour requirements against which a given staff grouping is applied; multiplying the total work-hours by the adjustment factor; and dividing by 2,080 hours (i.e., regular hours per person per work year). Any fraction of a staff member should be evaluated to determine whether an additional staff member (and hence reduced overtime) or increased overtime should be used to cover the work.

### Supervision

Supervision requirements should be determined based on local policy, job responsibility, and mechanic skill levels. Although the research evaluated supervision requirements, no norm was established because survey agencies deviated substantially from one another. In the survey group, cleaning and servicing supervision-to-staff ratios ranged from 1:5 to 1:35, with a mean of 1:8. Supervisor-to-mechanic ratios ranged from 1:4 to 1:14, with a mean of 1:6. An agency should evaluate its existing ratio accordingly, and consider using it to determine supervisory needs provided circumstances are not expected to change.

For purposes of illustration, an example application of the manpower planning model is included in Appendix A.

## ASSESSMENT OF LIMITATIONS

This research project analyzed detailed maintenance manpower requirements at 15 transit agencies and resulted in the development of an uncomplicated manpower planning model. The model is applicable to any transit agency for the purpose of estimating current and future labor requirements, and for evaluating existing labor utilizations against the range reported by the survey group. While the entire analysis was guided by sound research principles, and the results are conservatively stated, there are some limitations inherent in the maintenance manpower planning model. The user of the model should be cognizant of the potential limitations, as discussed below.

### Constrained Sample Size

The labor requirements analysis was based on a rigorous investigation of the diesel bus maintenance activities at 15 transit agencies. Although the sample was not randomly selected, every reasonable effort was made to achieve a representative cross-section of public transit agencies for the maintenance and servicing of transit buses. More than 50 transit agencies were contacted, and the 15 selected were evenly distributed geographically, by fleet size and by climatic conditions. Even so, the sample had two absolute constraints:

a. The agency had to be able to provide the disaggregate data required.

b. The agency had to be willing to spend the time to provide it.

While the researchers do not believe that these constraints invalidate the findings, there is no numeric data to confirm or refute comparability with those agencies without detailed labor data. The experience of the research team, and the relatively congruous results of the analysis suggest that the data are reflective of the industry. In comparing any one system to the study results, one should be careful to examine the mean as well as the standard deviation of the reported man-hour requirements.

**Data Availability**

Data availability was a concern in some cases, even in the survey group. In many cases, historical data were unavailable for a small number of job activities. In these instances, the research team interviewed supervisors and foremen to acquire time estimates. The estimates were compared with data provided from other agencies, and follow-up interviews were conducted where major discrepancies occurred.

In areas where actual reported times were available (e.g., at properties with work order based systems), some problems generally occurred in mechanic time reporting. For example, a mechanic might log on for one job, find another problem and fix it, and then log off with all work assigned to the initial task. Although this may impose some degree of inaccuracy, it is expected that much of this balances out at the more aggregate levels (e.g., vehicle subsystem) analyzed in this report.

**Subfleet Analysis**

Initially, it was attempted to obtain data on each model of bus produced by the different bus manufacturers. It was found that most of the agencies could not compile data at this level but grouped buses by similar type. For example, standard transit coaches produced by the General Motors Corporation from the early 1960's through 1978 were treated by most agencies as a single bus type even though the agencies' subfleets consisted of several of the different models. Similarly, data were not available on 30-ft and 35-ft models of the different manufacturers but were grouped with standard 40-ft transit buses. Further, several bus types were excluded from the subfleet analysis because of lack of data (e.g., Neoplans and Gillig Phantoms had been in service less than one year at two agencies), and/or only one property reported on the fleet type. In either case, the data were not considered to be reasonably representative of what might be expected in terms of manpower requirements.

Another important consideration is that the subfleet analysis examined what was reported and not why the labor requirements occurred. While most of the survey properties could identify what hours were spent repairing each fleet, they could not identify the specific operating characteristics of that subfleet (e.g., average speed by vehicle type). Other factors which were not quantified include mechanic training with particular subfeets, equipment availability, and facility adequacy (e.g., two properties maintained articulated vehicles in facilities designed for 40-ft buses). Therefore, when using the information, it is important to examine both the mean and standard deviation of the results.

**Multi-Divisional Impacts**

It was not possible to evaluate some of the parameters below the summary level at the medium and large agencies. The operating divisions at these multi-facility authorities may have widely varying service characteristics but not enough of them could provide data for comparison. One agency reported that average speed of buses in revenue service varied from a high of over 18 miles per hour to a low of 10 miles per hour at its different divisions and was an important consideration in maintenance manpower allocations. Facility layout can also impact servicing and hostling requirements at different garages in the same agency. Comparing any one division to the systemwide characteristics presented should be done with this in mind.

**Performance Evaluation**

As in any peer group comparison, the analyst should use the group norms and deviations to bracket a range of anticipated performance. Anytime a given property falls away from the norm, the analyst should ask the question why. Mitigating circumstances may render wide deviations as acceptable levels of performance. When a justification for a major deviation is unclear, the analyst should investigate that area for potential improvements.

CHAPTER FOUR

# CONCLUSIONS AND SUGGESTED RESEARCH

## CONCLUSIONS

Until recent years the transit industry, in general, was satisfied with maintenance reporting systems that tracked maintenance costs on a per mile basis and a few key indicators of overall performance. Typically, the cost of efficiency at which performance levels were achieved was not a matter of interest. However, pressures on transit managers from funding agencies to reduce the growth in operating subsidies have initiated efforts across the country to make maintenance organizations more productive. Manual record-keeping systems generally cannot react to maintnenace managers' needs for current information summarized in a usable manner to identify problem areas and to aid them in their decision-making. As a result, maintenance management systems are currently in a state of rapid transition to computerized reporting systems, many of which track man-hour and material expenditures by individual repair.

### Increasing Data Availability

Data availability for maintenance manpower planning studies is rapidly increasing. Leaders in the efforts to develop computerized maintenance management information programs have in-place systems that capture light maintenance repair data from individual work orders and have accumulated, in some instances, up to three years of vehicle repair histories. Several others have had their systems operational just over a year. Additionally, efforts are underway to include heavy repair functions and to provide the capability to allocate component rebuild labor to various bus types. These data can support sophisticated manpower leveling analyses geared toward efficient use of labor resources.

### Use of Labor Standards

Labor standards are not commonly used in the public transit industry to measure individual or group productivity. In the past, money has not been available to conduct time and motion studies or to extract data from manual reporting systems. Work histories are now being accumulated at agencies with computerized systems. As this number grows, the data base will increase dramatically. Four of the agencies participating in this study have initiated programs to develop labor standards at the detailed task level for the buses in their fleets. There is little coordination between these agencies.

## SUGGESTED RESEARCH

### Common Definition of Vehicle Systems and Work Tasks

A common breakdown of vehicle systems is needed within the transit industry. Each agency has developed its own definitions over a period of time. While there is some common ground, there are wide differences. Discussions with maintenance managers on their listings yielded a common response in many instances: "That is the way we have always done it."

Work task definitions also vary. In interviewing maintenance personnel about time to perform individual tasks, wide variances in responses were given initially. Once tasks were clearly defined, wide agreement was found. Commonly, time to diagnose a component failure was combined with time to replace the component. Development of a standard or widely accepted definition of primary work tasks would enhance industry communications and peer comparisons for maintenance performance.

### Continuing Need for Manpower Studies

This study should be considered only as the first step in understanding maintenance manpower planning. The industry is constantly changing.

New Buses

Several new buses have entered service in the past year. Large subfleets of Neoplan and Gillig Phantom standard transit coaches were being operated at some of the participating agencies, but they had been in service for less than a full year. For this reason, they were not included in the study.

Small Buses

The study did not include 30-ft transit coaches used frequently in smaller cities where passenger loads do not justify larger buses. Several manufacturers supply this type of bus, and the number in service is growing rapidly. More detailed analyses of vehicle impacts on maintenance manpower requirements would be of great assistance to transit systems in maintenance staffing.

### Unreported Maintenance Manpower

Large and medium sized agencies on the average accounted for 82 percent of their available maintenance manpower. This study did not address the reasons for the unreported time but only acknowledged that it must be included in manpower planning. While several subjective explanations were offered during the interview process, it was not possible to substantiate them.

Since the unaccounted time was almost as large as that devoted to preventive maintenance inspections, a study of the causes may lead to some of the productivity improvements needed by the industry. Accountability is of grave concern to transit operators faced with constrained resources for meeting transit needs. Improvements in labor utilization can serve to enhance in-service performance while reducing overall maintenance costs.

### Opportunity for Computerization

The increasing availability of automated maintenance data bases offers the opportunity for sophisticated maintenance manpower planning based on task level assignments. Supported by a detailed work order information system, the manpower planning model can be time-sensitive and incorporate performance and risk assessments. While such a model would be likely to exceed industry needs at the present time, industry trends suggest that it may be a viable alternative in a couple of years.

### Materials Planning Comparable

A process similar to the research approach used here for manpower could be used to analyze maintenance materials requirements. Properties across the nation have experienced unprecedented growth in materials costs over the past several years. Materials are generally stocked at levels which ensure parts availability without much emphasis on holding cost. Confronted with constrained financial resources, the area of maintenance materials cost proffers the opportunity for significant return. An integrated manpower and materials planning model could be established at a relatively uncomplicated level, and it appears to be a logical step in controlling maintenance resources.

## APPENDIX A
## AN EXAMPLE OF MODEL APPLICATION

### Introduction

An example application of both the graphical and numerical approach to the manpower planning model is detailed in this appendix for illustratrive purposes. The model is applied to a fictitious property, known as the Garden of Eden Transit Authority. The results produced from the graphic solutions and numerical calculations are compared to identify potential differences.

### Transit Property Characteristics

The Garden of Eden Transit Authority (Eden Transit) is located in the southeastern United States. Eden Transit owns and operates 857 buses out of four light maintenance facilities. The system operates in a hot and humid summer climate, and moderate winter climate. The Eden Transit fleet and operating characteristics are presented in Table A-1. Each vehicle is equipped with a mechanical farebox and an electronic destination sign.

**TABLE A-1**
**GARDEN OF EDEN TRANSIT AUTHORITY CHARACTERISTICS**

Fleet Size: 857
Annual Miles: 33,100,000

Fleet Composition:

| Number | Manufacturer | Transmission | Annual Miles |
|---|---|---|---|
| 500 | GMC New Look | VH&VS | 19,300,000 |
| 265 | Flxible | V730 | 10,200,000 |
| 92 | RTS | V730 | 3,600,000 |

| | |
|---|---|
| Peak Vehicle Requirement: | 755 |
| Accident Rate: | 32/million miles |
| Wheelchair Lift-Equipped Buses: | 250 |
| Paid Coffee Breaks: | 2 per shift at 15 minutes each |
| Clean-Up Time: | 10 minutes per shift |
| Holidays: | 10 days |
| Average Maintenance Vacation: | 10 days |
| Absence/Sick Leave: | 15 days per employee |
| Other Absence Days: | 3 days per employee |
| Percent Overtime: | 3% |

### Graphical Solution to Manpower Requirements

Given the basic operating characteristics of Eden Transit, one can analyze maintenance manpower requirements using the nomographs, a straight edge, and a few simple calculations. The following paragraphs discuss the steps for graphical model application, as done for Eden Transit.

Starting with the cleaning and servicing nomograph, a straight line is drawn from the number of peak vehicles (i.e., 755), through the focal point. The man-hour scale intercept is 105,000 hours, as shown in Figure A-1.

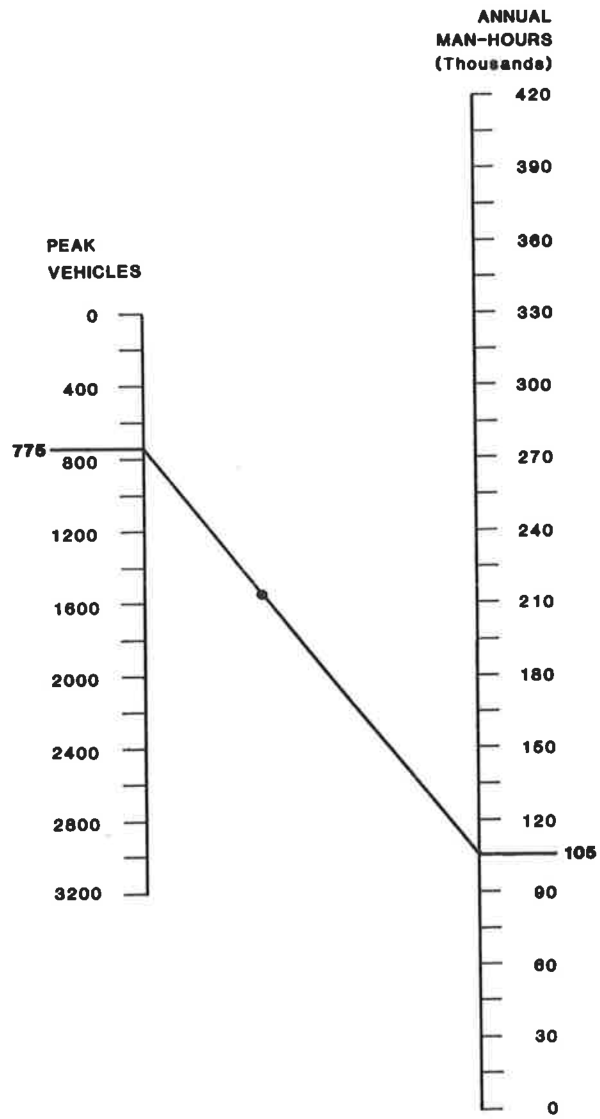


Figure A-1. Graphic solution to cleaning and servicing man-hours.

In the example, the minor inspection was replaced by a major inspection every fourth cycle, so the man-hours here were further multiplied by 0.75 to adjust for this (Table A-2). Total inspection hours is the sum of hours for each inspection type.

TABLE A-2
SOLUTION TO INSPECTION MAN-HOURS

Inspection Program:

| Inspection | Frequency | Job Time |
|---|---|---|
| Safety | 1,000 miles | 15 minutes |
| Minor | 6,000 miles | 4 hours |
| Major | 24,000 miles | 10 hours |

Inspection Hours Calculation:

Safety: 0.25 hours * (33,100,000 miles/1,000 miles) = 8,275 hours

Minor: 4 hours * (33,100,000 miles/6,000 miles) * 0.75 = 16,550 hours

Major: 10 hours * (33,100,000 miles/24,000 miles) = 13,792 hours

Total: 38,617 hours

Because of the wide variation in inspection policies, man-hours for this activity are built up separately for each agency. This is accomplished by defining the frequency and work time requirement for each inspection type used (e.g., safety, minor, major, and statuatory), as shown in Table A-2. Eden Transit conducts a minor inspection every 6,000 miles for three inspections, then at 24,000 miles a major inspection is conducted. The calculation is as follows:

$$\sum_i \sum_j \text{Hours to Perform}_{ij} * \left( \text{Annual Miles}_j \; / \; \text{Miles Between Inspections}_{ij} \right)$$

Where:

i = Inspection type

j = Vehicle type

Man-hours for body work are found using the nomograph in Figure A-2, by drawing a straight line from the annual miles scale (i.e., 33,100,000), through the accident frequency (i.e., 32 accident/million miles). The annual body hours intercept is the total job requirement (i.e., 59,000 hours).

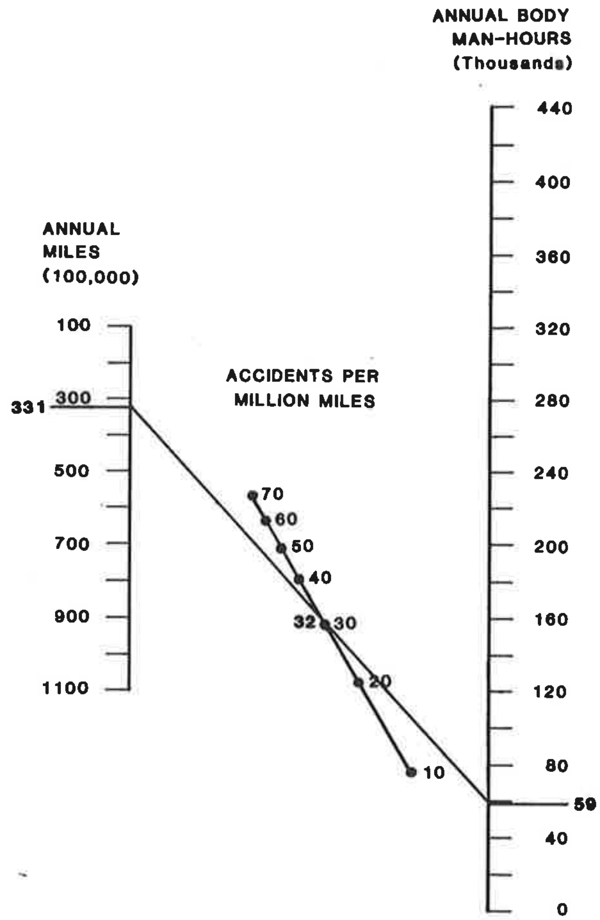


Figure A-2. Graphic solution to body man-hours.

Engine and fuel hours are evaluated on a subfleet level, as depicted in Figure A-3. For each respective subfleet, a line is drawn from the subfleet's annual mileage (left scale), through the respective subfleet's focal point. The intercept on the right scale is the annual man-hour requirement for the corresponding subfleet. In the example, Eden Transit has GMC new look, Flxible, and RTS II buses. This requires that two lines be drawn (Flxible and RTS share the same focal point) to determine total work-hours.

Braking hours are also analyzed on a subfleet level. In this case, three lines are drawn from each subfleet's mileage, through the corresponding focal point, as shown in Figure A-4. The right scale intercept defines man-hour requirements (i.e., RTS-4000; FLX-10,000; GMC-28,000 hours).

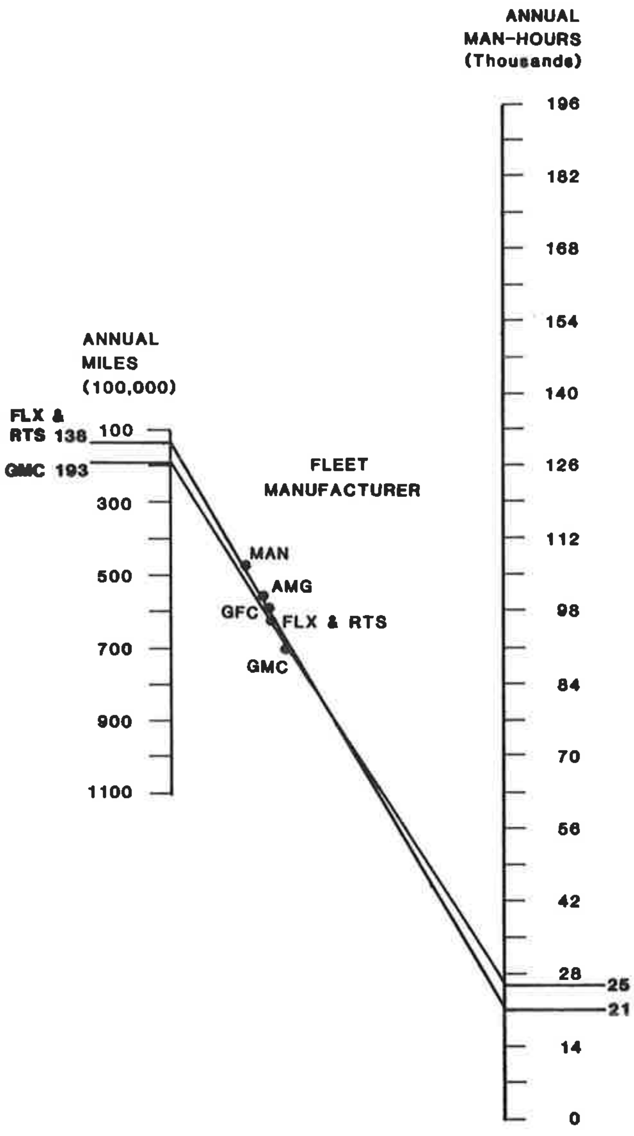


Figure A-3. Graphic solution to engine and fuel man-hours.

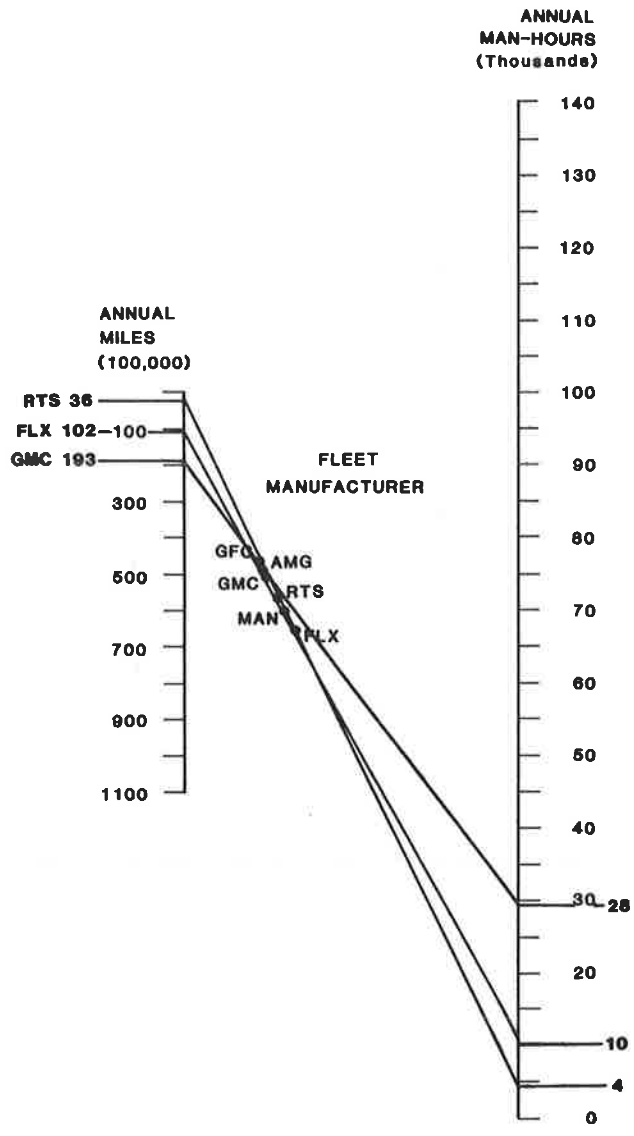


Figure A-4. Graphic solution to braking man-hours.

Electrical work requirements are estimated using the nomograph illustrated in Figure A-5. The analysis is done at the subfleet level by drawing a straight line from each fleet's annual mileage, through the respective focal point. The right scale intercept provides man-hours (i.e., 11,000 hours for FLX; and 21,000 hours for RTS and GMC in the example).

The graphic solution to air, steering, and suspension man-hours is found by drawing a straight line from the appropriate fleetwide mileage number on the left scale, through the focal point. The right scale intercept, as shown in Figure A-6, provides the work-hour requirement (i.e., 25,500 in the example).

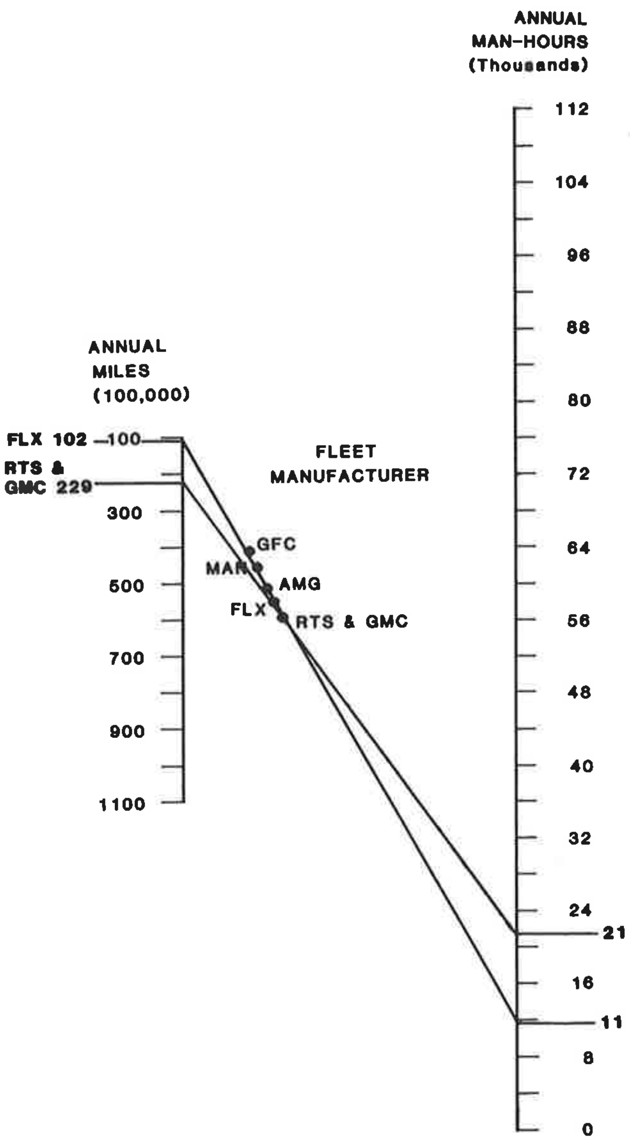


Figure A-5. Graphic solution to electrical man-hours.

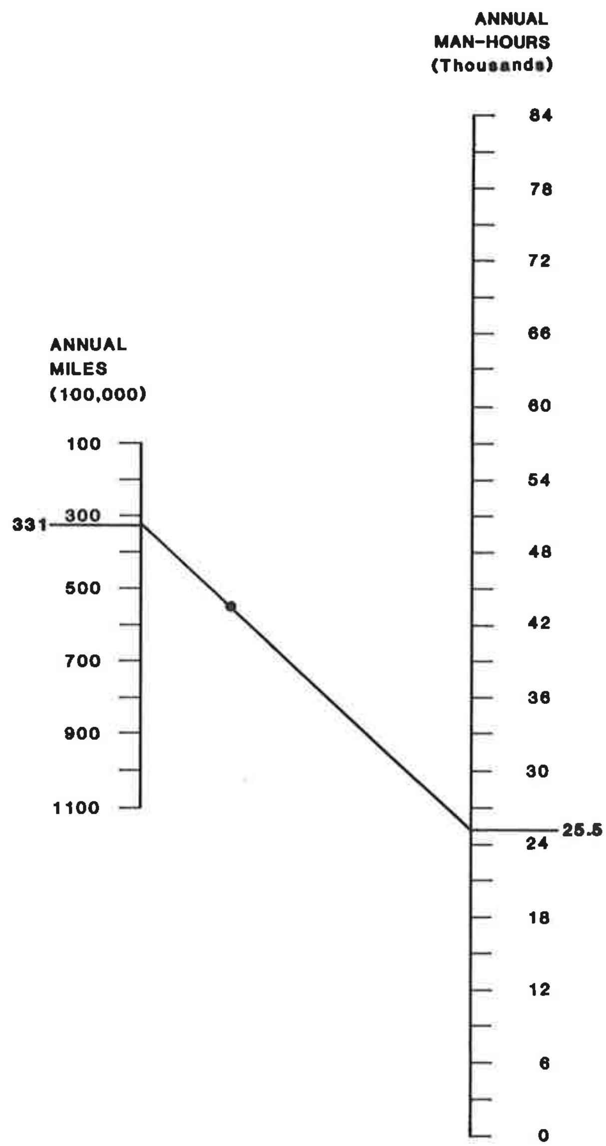


Figure A-6. Graphic solution to air, steering, and suspension man-hours.

Air conditioning and heating labor-hours are a function of miles and summer climate. Hours are found by drawing a straight line from the appropriate point on the mileage scale, through the focal point corresponding with local summer climate (i.e., hot and humid in the example on Figure A-7). The intercept with the right scale is the annual labor-hour requirement (i.e., 56 hours in the example).

Drivetrain maintenance requirements are analyzed at the subfleet level, as shown in Figure A-8. A straight line is drawn from the mileage intercept (left scale), through the corresponding transmission type for each category. The right scale intercept provides annual labor-hour needs (i.e., 8,000 hours for the V730; and 26,000 hours for the VH and VS).

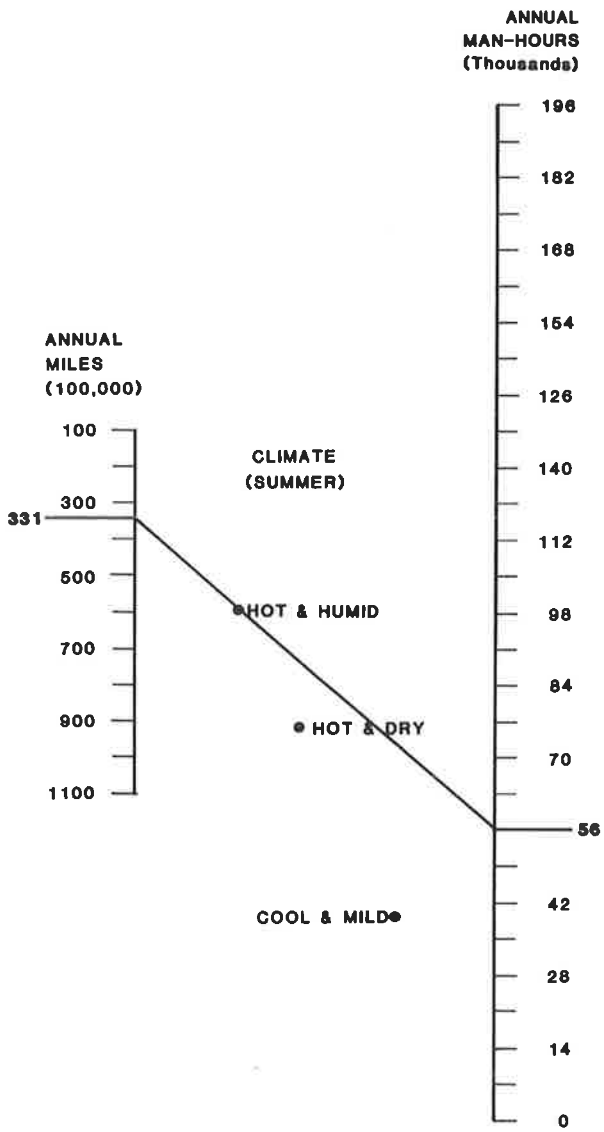


Figure A-7. Graphic solution to air conditioning and heating man-hours.

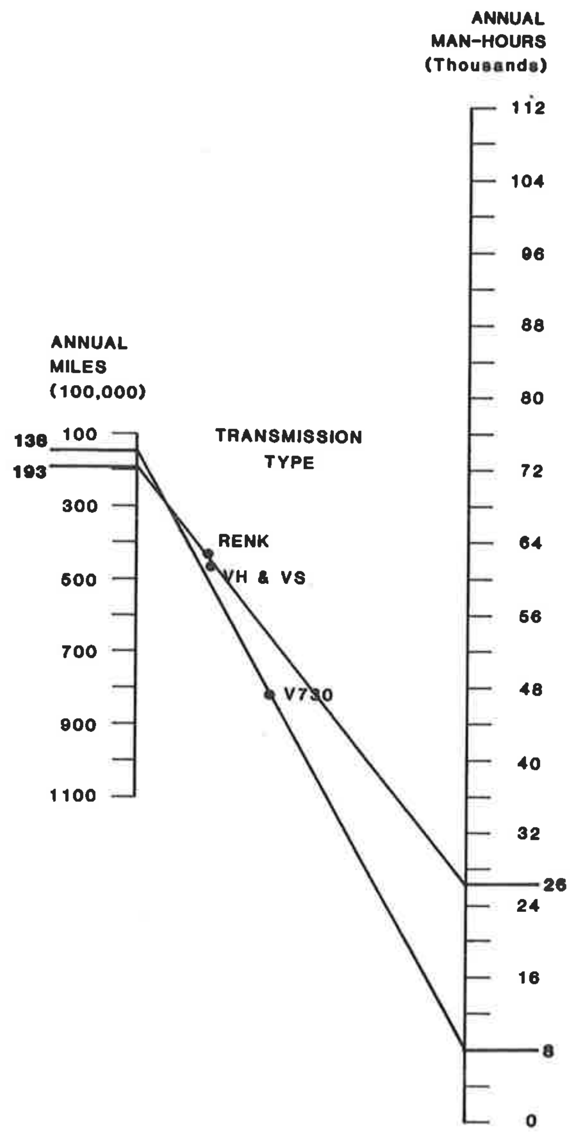


Figure A-8. Graphic solution to drivetrain man-hours.

Cooling labor requirements are estimated at the systemwide level based on mileage and summer climate. A straight line is drawn from the annual mileage figure, through the focal point corresponding with local summer climate (i.e., in the example on Figure A-9 the climate is hot). The right scale intercept represents labor requirements in hours (i.e., 22,000 in the example).

Wheels and tires labor-hours are only calculated if some maintenance man-hours are devoted to these areas. Eden Transit does conduct all remove and replace and some tire repair in-house. The nomograph in Figure A-10 is used by drawing a straight line from the appropriate mileage intercept, through the focal point. The hours intercept in the example is 16,000 hours.

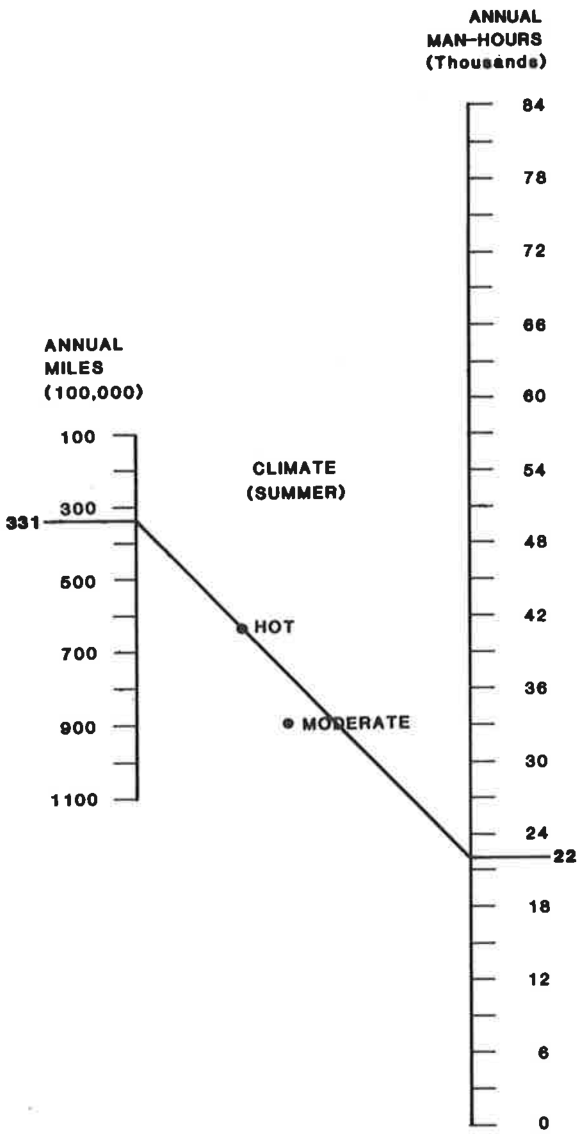


Figure A-9. Graphic solution to cooling man-hours.

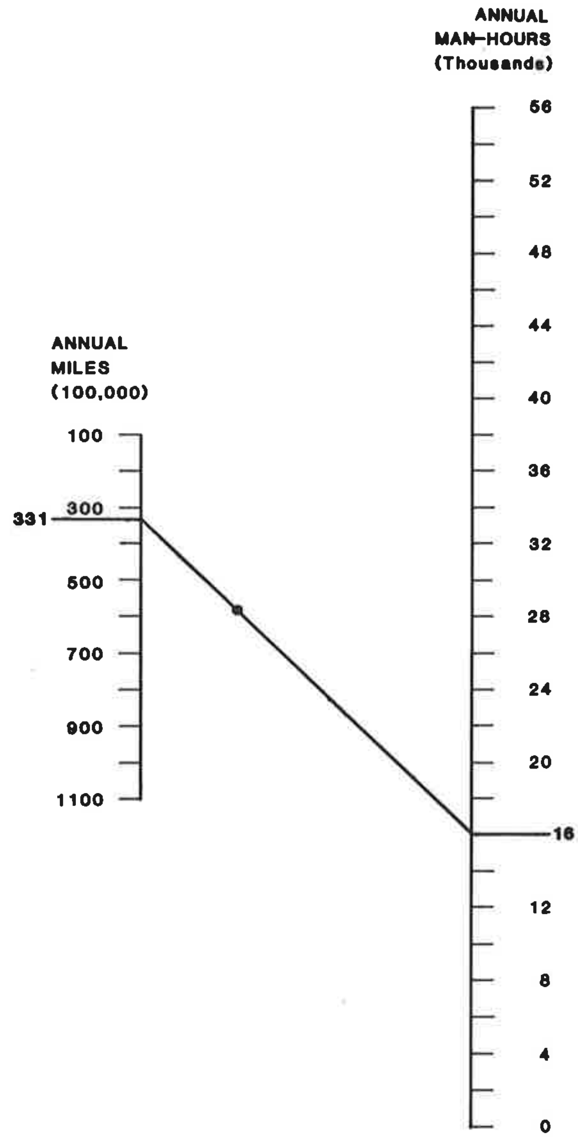


Figure A-10. Graphic solution to wheels and tires man-hours.

Labor-hours for accessories are estimated separately by major component. For example, Eden Transit contracts out for all radio repair, therefore no calculation is needed. Farebox work is done in-house, and the nomograph in Figure A-11 can be used to estimate labor-hours. A straight line is drawn from the number of peak vehicles (i.e., 755 in the example), through the focal point. The result is 8,000 man-hours per year.

Eden Transit has electronic destination signs on all of its vehicles. Repair hours for these signs is found by using the nomograph in Figure A-12. A straight line is drawn from the number of peak vehicles (i.e., 755 in the example), through the appropriate focal point (i.e., electronic in the example). The right scale intercept, 4,000 hours, is the annual labor requirement.

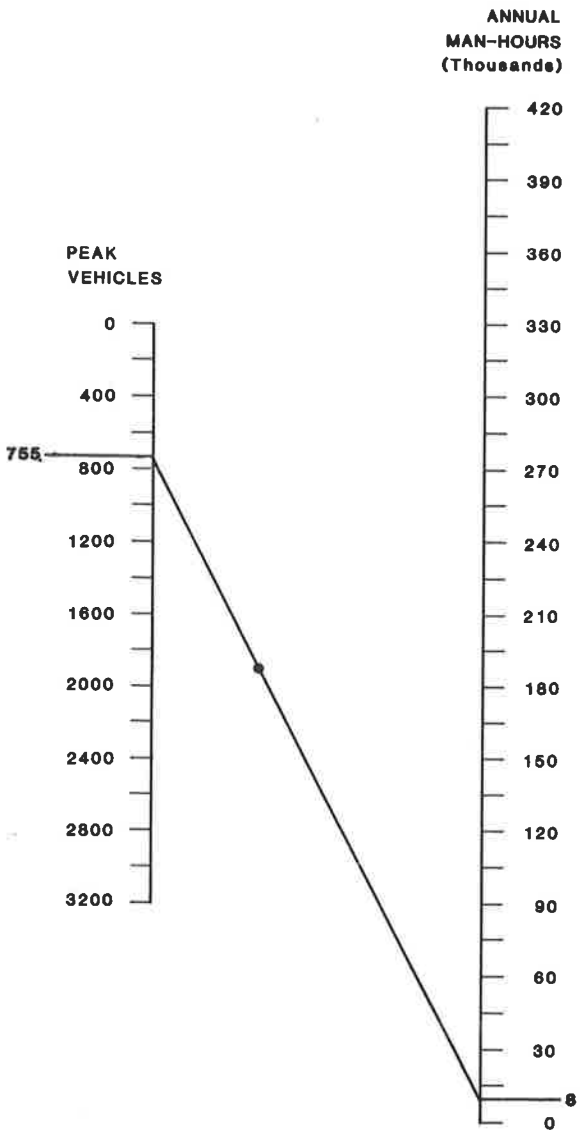


Figure A-11. Graphic solution to farebox man-hours.

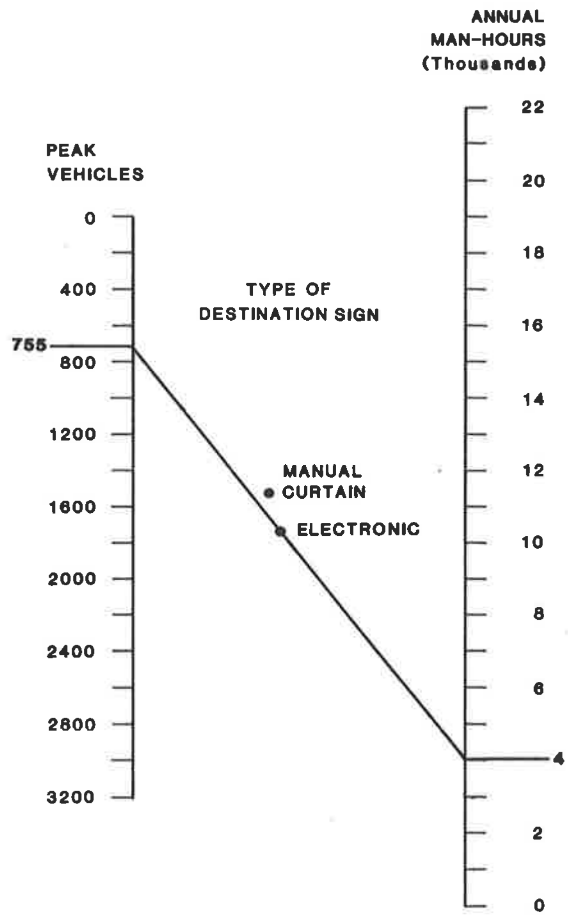


Figure A-12. Graphic solution to destination sign man-hours.

Eden Transit has 250 coaches equipped with wheelchair lifts. Maintenance hours are found by drawing a line from the number of lift equipped buses through the focal point, as shown in Figure A-13. The right scale intercept, 3500 hours, is the annual labor requirement.

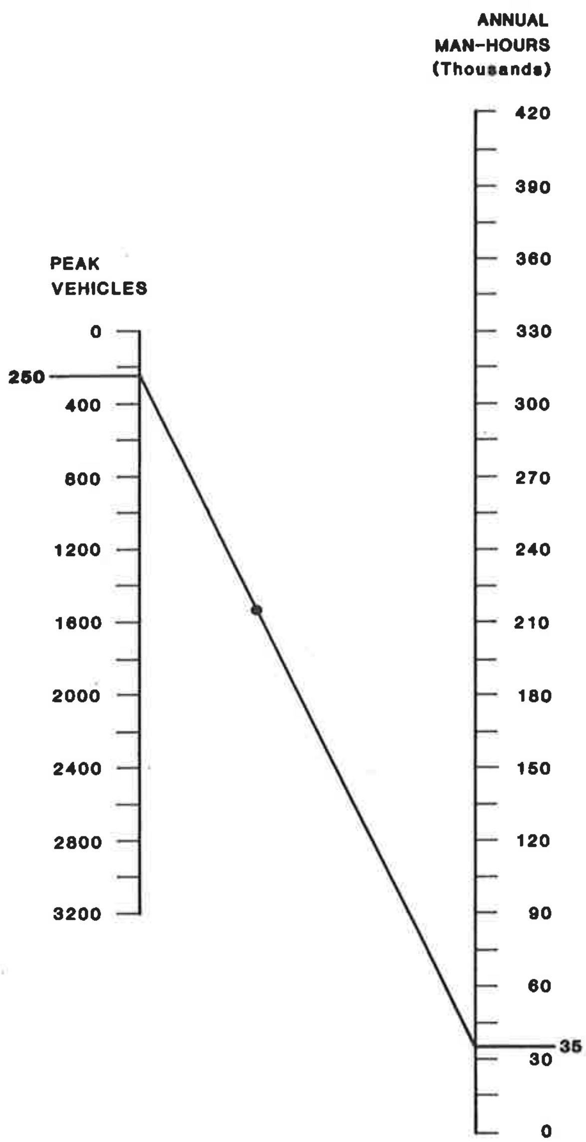


Figure A-13. Graphic solution to wheelchair lift man-hours.

Now that each function and vehicle subsystem have been addressed, all the individual labor-hour estimates are summed, as shown in Table A-3. The total represents work-hour requirements. This number must be expanded by unavailable time to determine actual staffing requirements.

TABLE A-3
TOTAL WORK-HOUR REQUIREMENT

| | |
|---|---|
| Cleaning and Inspection | 105,000 |
| Inspection | 38,600 |
| Body | 59,000 |
| Engine and Fuel | |
| FLX & RTS | 21,000 |
| GMC | 25,000 |
| Braking | |
| RTS | 4,000 |
| FLX | 10,000 |
| GMC | 28,000 |
| Electrical | |
| FLX | 11,000 |
| RTS & GMC | 21,000 |
| Air, Steering, and Suspension | 25,500 |
| Air Conditioning, Heating, and Ventilation | 56,000 |
| Drivetrain | |
| VH & VS | 26,000 |
| V730 | 8,000 |
| Cooling | 22,000 |
| Wheel and Tires | 16,000 |
| Accessories | |
| Farebox | 8,000 |
| Destination Sign | 4,000 |
| Wheelchair Lift | 3,500 |
| **TOTAL** | **491,600** |

Work-hour adjustments are determined using two nomographs, one for unavailable time and one for overtime. The graphic solution for unavailable time draws a straight line from daily minutes unavailable (i.e., two 15-minute breaks and 10 minutes clean-up yields 40 minutes), through the number of days unavailable per year (i.e., 38 in the example), as shown in Figure A-14. The intercept with the right scale provides the expansion factor (i.e., 1.275 in the example).

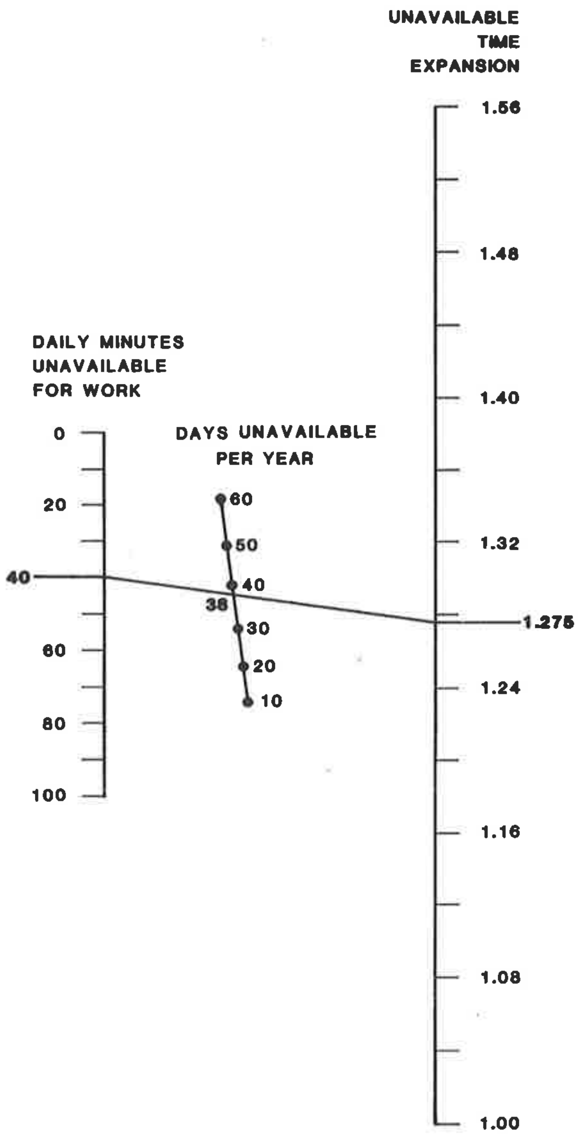


Figure A-14. Graphic solution to unavailable time expansion.

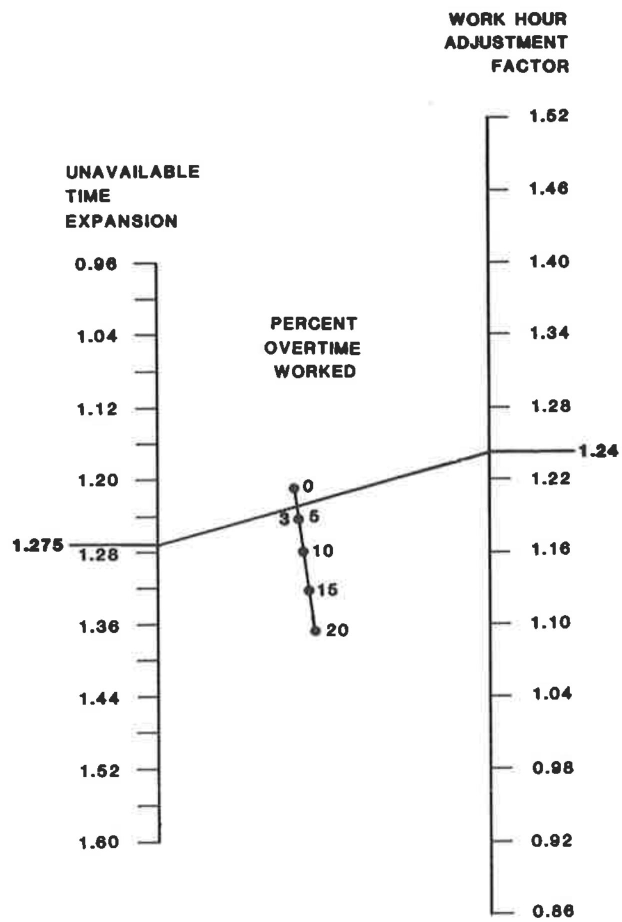


Figure A-15. Graphic solution to overtime adjustment.

If overtime is routinely used to conduct maintenance work, the adjustment factor should reflect this. The nomograph in Figure A-15 does this by drawing a line from the expansion factor (calculated in the previous graph) through the annual percent of overtime worked (center scale). The right scale intercept is then used as a multiplier to the total work-hour requirement.

The total work-hour requirement is multiplied by the adjustment factor, and the result is divided by 2,080 hours to yield staff requirements. The calculation may be done for the entire maintenance function or separately for each activity area assigned to a dedicated staff. In the example, Eden Transit has separate servicing and mechanic staffs, as shown in Table A-4. If comparing this number to actual staffing levels, the numbers should be within 10 percent of one another.

TABLE A-4
CALCULATION OF STAFFING REQUIREMENT

| | | |
|---|---|---|
| Total Maintenance Staff Needs | | |
| Total Work-Hours | 491,600 | |
| Adjustment Factor | *1.24 | |
| Total Staff Hours | 609,584 | |
| Hours/Person/Year | ÷ 2,080 | |
| Maintenance Staff | 293 | |
| Total Servicing Staff Needs | | |
| Total Work-Hours | 105,000 | |
| Adjustment Factor | *1.24 | |
| Total Staff Hours | 130,200 | |
| Hours/Person/Year | ÷ 2,080 | |
| Maintenance Staff | 62.60 | or 63 |
| Total Mechanic Staff Needs | | |
| Total Work-Hours | 386,600 | |
| Adjustment Factor | *1.24 | |
| Total Staff Hours | 479,384 | |
| Hours/Person/Year | ÷ 2,080 | |
| Maintenance Staff | 230.47 | or 231 |

Mathematical Solution to Manpower Requirements

As an alternative to using nomographs, the maintenance manpower estimate can be prepared by mathematical algorithm. The algorithm presented in Chapter Three is applied against the operating characteristics of Eden Transit in the following paragraphs.

The mathematical solution to maintenance manpower is built up by each function and vehicle subsystem, as shown in Table A-5. The calculations are straightforward, and involve applying the Eden Transit operating characteristics (previously presented in Table A-1) to the formulas detailed in Chapter Three. In the example, the mean maintenance times from the research are used to estimate manpower. A more detailed analysis could also be conducted using the standard deviations presented in Chapter Three.

TABLE A-5
MATHEMATICAL SOLUTION TO WORK-HOUR REQUIREMENTS

1. Servicing Hours
755 peak vehicles * 128.5 hours/vehicle = 104,568 hours

2. Inspection Hours

| | |
|---|---|
| Safety: | 0.25 hours * (33,100,000 miles/1,000 miles) = 8,275 hours |
| Minor: | 5 hours * (33,100,000 miles/6,000 miles) * 0.75 = 16,550 hours |
| Major: | 10 hours * (33,100,000 miles/24,000 miles) = 13,792 hours |
| Total: | 8,275 + 16,550 + 13,792 = 38,617 hours |

3. Body Hours
33,100,000 miles/100,000 miles * (5.5 hours * 32 accidents/million miles) = 58,256 hours

4. Engine/Fuel Hours

| | |
|---|---|
| GMC | 19,300,000 miles * 130 hours/100,000 miles = 25,090 hours |
| FLX | 10,200,000 miles * 155 hours/100,000 miles = 15,810 hours |
| RTS | 3,600,000 miles * 156 hours/100,000 miles = 5,616 hours |
| Total | 25,090 + 15,810 + 5,616 = 46,516 hours |

5. Braking Hours

| | |
|---|---|
| GMC | 19,300,000 miles * 147 hours/100,000 miles = 28,371 hours |
| FLX | 10,200,000 miles * 102 hours/100,000 miles = 10,404 hours |
| RTS | 3,600,000 miles * 125 hours/100,000 miles = 4,500 hours |
| Total | 28,371 + 10,404 + 4,500 = 43,275 hours |

6. Air, Steering and Suspension Hours
33,100,000 miles * 76.5 hours/100,000 miles = 25,322 hours

7. Electrical Hours

| | |
|---|---|
| GMC | 19,300,000 miles * 93 hours/100,000 miles = 17,949 hours |
| FLX | 10,200 miles * 101 hours/100,000 miles = 10,302 hours |
| RTS | 3,600,000 miles * 92 hours/100,000 miles = 3,212 hours |
| Total | 17,949 = 10,302 = 3,312 = 31,563 hours |

8. Air Conditioning, Heting and Ventilation
Hot & Humid 33,100,000 miles * 168.5 hours/100,000 miles = 55,773 hours

9. Drivetrain Hours

| | |
|---|---|
| VH & VS | 19,300,000 miles * 135 hours/100,000 miles = 26,055 hours |
| V730 | 13,800,000 miles * 58 hours/100,000 miles = 8,004 hours |
| Total | 26,055 = 8,044 = 34,059 hours |

10 Cooling Hours

| | |
|---|---|
| Hot | 33,100,000 miles * 65 hours/100,000 miles = 21,515 hours |

11 Wheels and Tires Hours
33,100,000 miles * 48.6 hours/100,000 miles = 16,087 hours

12 Accessories Hours

| | |
|---|---|
| Farebox | 755 vehicles * 11.0 hours/vehicle = 8,305 hours |
| Destination Sign | 755 vehicles * 6.0 hours/vehicle = 4,530 hours |
| Wheelchair Lift | 250 vehicles * 14.7 hours/vehicle = 3,675 hours |
| Total | 8,305 + 4,530 = 3,675 = 16,510 hours |

Once work-hour estimates by subsystem and function are complete, the results of each are totalled, as shown in Table A-6. This amount represents work requirements, and therefore must be expanded by unavailable time prior to estimating staffing levels. Unavailable time occurs both on the job (e.g., break and clean-up time) and off the job (e.g., holidays, sick leave). The formula for expanding manpower, presented in Table A-7, results in a factor of 1.277 for Eden Transit.

The use of overtime also impacts staffing needs by reducing the number of bodies needed to do the same work. Eden Transit routinely uses 3 percent overtime, which reduces the adjustment factor to 1.239.

TABLE A-6
TOTAL WORK-HOUR REQUIREMENT

| | |
|---|---|
| Cleaning and Servicing | 104,568 |
| Inspection | 38,617 |
| Body | 58,256 |
| Engine/Fuel | 46,516 |
| Braking | 43,275 |
| Electrical | 31,563 |
| Air, Steering and Suspension | 25,322 |
| Air Conditioning, Heating and Ventilation | 55,773 |
| Drivetrain | 34,059 |
| Cooling | 21,515 |
| Wheel & Tires | 16,087 |
| Accessories | 16,510 |
| TOTAL | 492,061 |

TABLE A-7
WORK-HOUR ADJUSTMENT FACTOR

Unavailable Time

Expansion Factor = 8 hours/ (8 hours - 40 minutes) * 260 days/ (260 days - 38 days) = 1.277

Overtime

Adjustment Factor = 1.277 * (1-0.03 overtime) - 1.239

The translation of work-hours into staffing hours work the same as previously discussed for nomographs. Total work-hours are multiplied by the adjustment factor, and the product is divided by 2,080 hours. The quotient is the staffing requirement. This analysis can be done at the systemwide level, or for any functional area with a dedicated staff (e.g., servicing, body). Eden Transit has two labor pools: servicers and mechanics. The staffing calculation for each is given in Table A-8.

Comparison of Results

Use of the nomographs to estimate manpower may be expected to result in some loss of accuracy due to visual interpretation of intermediate points on the graphs. However, scales were drawn with the intent of minimizing this error. In the Eden Transit example, the two estimates (i.e., graphic and numeric) were performed separately and they produced essentially the same results. While some minor differences occur at the subsystem level, total maintenance staff was estimated at 293 persons by both techniques. When applied separately for servicers and mechanics, both estimated 231 persons for mechanics. However, primarily because of rounding differences, the nomographs estimated 63 servicers and the mathematical algorithm estimated 62 servicers.

The primary difference between the two techniques is the time requirement in application. The nomographs required only 20 minutes to complete, while the formulas took about 40 minutes. It may be easier to use the nomographs for cases where system characteristics conform with those presented in Chapter Three. If one wishes to conduct a more detailed variance analysis involving standard deviations and such, the formulas provide more flexibility.

TABLE A-8
CALCULATION OF STAFFING REQUIREMENT

| | | |
|---|---|---|
| Total Maintenance Staff Needs | | |
| Total Work-Hours | 492,061 | |
| Adjustment Factor | *1.239 | |
| Total Staff Hours | 609,663 | |
| Hours/Person/Year | ÷ 2,080 | |
| Maintenance Staff | 293.1 | or 293 |
| Total Servicing Staff Needs | | |
| Total Work-Hours | 104,568.0 | |
| Adjustment Factor | *1.239 | |
| Total Staff Hours | 29,559.8 | |
| Hours/Person/Year | ÷ 2,080 | |
| Maintenance Staff | 62.3 | or 62 |
| Total Mechanic Staff Needs | | |
| Total Work-Hours | 387,493 | |
| Adjustment Factor | *1.239 | |
| Total Staff Hours | 480,104 | |
| Hours/Person/Year | ÷ 2,080 | |
| Maintenance Staff | 230.8 | or 231 |

APPENDIX B
DATA COLLECTION GUIDE

GENERAL AGENCY INFORMATION

1. Annual mileage, miles operated per year .........
2. Revenue service miles, miles per week ...........
3. Revenue service hours, hour per week ............
4. Peak hour, maximum buses scheduled ............
5. Active fleet avail. for scheduled service..........
6. Spare buses . . . number ........................
7. Base bus requirements . . . buses scheduled .......
8. Saturday requirements, max. buses scheduled .....
9. Sunday requirements, max. buses scheduled .......
10. Accident rate, accidents per million miles ........
11. Number of light maint. facilities, total ...........
12. Number of buses assigned to each facility,........
13. Road calls, miles between incidents..............
14. Wheelchair lift usage, passengers per week .......
15. Terrain - hilly, moderately hilly, flat ............
16. Summer climate ..............................
17. Winter climate................................

MAINTENANCE STAFFING INFORMATION

1. Management..................................
2. First level supervision ..........................
   - Running Repair ............................
   - Inspection..................................
   - Service/Cleaning............................
   - Component rebuild ..........................
   - Body/Paint .................................
3. Clerical.......................................
4. Mechanics, Master ...........................
5. Mechanics, Journeyman .........................
6. Mechanic, Apprentice..........................
7. Cleaners/Hostlers .............................
8. Average Seniority of Mechanics, years ..........

Comments:

Instructions:

1. Obtain organization chart if available
2. Determine the role, if any, of lead mechanics in supervision.
3. Obtain staffing matrix.

MAINTENANCE MANPOWER DATA

1. Annual vacation avg. days/person/year ...........
2. Sick leave, avg.days per person per year..........
3. Holidays, avg. days per person per year...........
4. Workmans comp., avg. days/person/year ..........
5. Other time off, avg. days/person/year............
6. Overtime, hours/year ...........................
7. Paid lunch breaks, minutes per shift .............
8. Paid coffee breaks, minutes per shift ............
9. Cleanup time, minutes per shift .................

Comment:

Instructions

1. Work rules specified in labor agreements as well as established "past practices" can have an impact on labor productivity. Determine through the interview process if there is any such impact in each agency.

MAJOR WORK ACTIVITIES

Service and Cleaning

1. Daily servicing : ........................

2. Major interior cleaning : average time ........... : frequency ..............
3. Chassis Wash : average time ........... : frequency ..............

Comments:

Instructions:

1. Obtain total man-hours used for daily servicing and cleaning of vehicles.

2. Determine number of vehicles serviced daily, Saturday, and Sunday.

3. Provide time spent in actual servicing and cleaning of a vehicle as shown above in order to separate time for circulation of vehicles.

**Inspection:**

1. Safety Inspection : time required ...........
   : frequency ..............
2. Minor Inspection : time required ...........
   : frequency ..............
3. Major Inspections: : time required ...........
   : frequency ..............
4. Statutory Insp. : time required ...........
   : frequency ..............
5. Repair time : man-hours per inspection .............

**Comments:**

**Instructions:**

1. Obtain copies of inspection procedures and check lists.
2. Obtain definition of each different type inspection.
3. Determine the average number of hours used for minor repairs during each inspection.
4. Obtain the total numer of personnel devoted to inspections.

**BUS SUBFLEET PROFILE**

1. Manufacturer ................................
2. Model ....................................
3. Number ....................................
4. Year of manufacturer or average age ...........
5. Engine ....................................
6. Transmission ..............................
7. Destination sign ............................
8. Air conditioner ............................
9. Fare box ..................................
10. Power steering ..............................
11. Wheelchair lift ..............................
12. Annual mileage of subfleet ....................

**Comments:**

**VEHICLE SYSTEMS DATA**

**General Instructions:**

1. Remove and replace times of components and assemblies should be reported in average man-hours to perform the task.
2. Component rebuild times should be reported in average number of hours to rebuild. It includes disassembly and parts cleaning unless otherwise specified.
3. Running repair times should be reported in man-hours per bus per year.
4. Frequency of rebuild activities should be reported in miles operated between events or number of rebuilds per year.
5. Determine if remove and replace times of components are included in running repair times.
6. Determine which, if any, components are rebuilt by an outside contractor.

**Systems: Accessories**

**Work Activity:**

Running repair : man-hours ............. per bus per year

Unit repair

1. Destination signs : remove and replace ......
   : repair .................
   : frequency .............
2. Farebox : remove and replace ......
   : repair .................
   : frequency .............
3. Radios : remove and replace ......
   : repair .................
   : frequency .............
4. Wheelchair lifts : remove and replace ......
   : repair .................
   : frequency .............

**Comments:**

**Instructions:**

**System: Air**

**Work Activity:**

Running repair : man-hours ............. per bus per year

Unit repair

1. Air compressor : remove and replace ......

| | | |
|---|---|---|
| | : | rebuild, average time .... |
| | : | frequency .............. |
| 2. Governor | : | remove and replace...... |
| | : | rebuild................. |
| | : | frequency .............. |
| 3. Air starters | : | remove and replace...... |
| | : | rebuild................. |
| | : | frequency .............. |
| 4. Misc. air components | : | man-hours.............. per bus per year |

**Comments:**

**Instructions:**

1. Air components include door motors, relay valves, application valves, pressure switches, windwhield wiper motors, shutters.

2. Determine if rebuild of air compressor and governors are included in misc. air component rebuild time.

**System: Air Conditioning**

**Work Activity:**

| | | |
|---|---|---|
| Running repair | : | man-hours.............. per bus per year |
| Unit repair | | |
| 1. Compressor | : | remove and replace...... |
| | : | rebuild................. |
| | : | frequency .............. |
| 2. Alternator | : | remove and replace...... |
| | : | rebuild................. |
| | : | frequency .............. |
| 3. Condensor | : | remove and replace...... |
| | : | repair ................. |
| | : | frequency .............. |
| 4. Misc. components | : | man-hours.............. per bus per year |

**Comments:**

**Instructions:**

1. Running repair should include annual inspections if performed.

**System: Body**

| | | |
|---|---|---|
| Running repair | : | man-hours.............. per bus per year |
| Major repair | : | ...................... |
| 1. Body | : | ...................... |
| 2. Painting | : | ...................... |
| 3. Upholstery | : | ...................... |
| 4. Glass repair | : | ...................... |

**Comments:**

**Instructions:**

1. Major Repair times should be in total man-hours per year per bus.

2. Running repair includes minor repairs on passenger doors, access panel replacement, battery racks repair, mirror replacement.

3. Indicate if absorption type bumpers are used.

4. Note if plastics or glass windows are used.

**System: Braking**

**Work Activity:**

| | | |
|---|---|---|
| Running repair | : | man-hours.............. per bus per year |
| Unit repair | | |
| 1. Front axle | : | reline.................. |
| | : | frequency .............. |
| 2. Drive axle | : | reline.................. |
| | : | frequency .............. |
| 3. Parking brake | : | reline.................. |
| | : | frequency .............. |
| 4. Third axle | : | reline.................. |
| (if applicable) | : | frequency .............. |

**Comments:**

**Instructions:**

1. Reline of brakes includes turning of drums, building shoes, reconditioning brake chambers and remove/replace of wheel package.

2. Air components are included under air system.

3. Brake adjustments are included in running repair.

**System:** Cooling

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair
1. Fan torus : remove and replace......
: rebuild.................
: frequency ..............
2. Radiator : remove and replace......
: repair .................
: frequency ..............
3. Surge tank : remove and replace......
: repair .................
: frequency ..............
4. Water pump : remove and replace......
: rebuild.................
: frequency ..............
5. Shutters : remove and replace......
: rebuild.................
: frequency ..............
6. Misc. repairs : man-hours..............
per bus per year

**Comments:**

**Instructions:**

1. The removal and replacement of hoses and piping is included in running repair.

**System:** Drivetrain

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair
1. Transmission : remove and replace......
: rebuild.................
: frequency ..............
2. Differential : remove and replace......
: rebuild.................
: frequency ..............

**Comments:**

**Instructions:**

1. Rebuild time should include tear down, cleaning, and rebuild of small accessories.

**System:** Electrical

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair
1. Starters : remove and replace......
: rebuild.................
: frequency ..............
2. Alternator/Generator : remove and replace......
: rebuild.................
: frequency ..............
3. Misc. elec. component : man-hours..............
per bus per year

**Comments:**

**Instructions:**

1. Time to remove/replace and recharge batteries are included in running repair.

2. Time to rebuild all miscellaneous electrical components should be reported in man-hours per year per bus.

**System:** Engine

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair
1. Engine : In-frame overhaul .......
: frequency ..............
2. Engine assembly : remove and replacement
: rebuild.................
: frequency ..............
3. Engine cradle assembly : Tear down/reassembly ...

4. Engine head : remove and replace......
: rebuild.................
: frequency ..............

5. Engine blower : remove and replace......
: rebuild.................
: frequency ..............

6. Engine turbocharger : remove and replace......
: rebuild.................
: frequency ..............

**Comments:**

**Instructions:**

**System: Fuel**

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair

1. Fuel pump : remove and replace......
: rebuild.................
: frequency ..............

2. Injectors : remove and replace......
: rebuild.................
: frequency ..............

3. Fuel tank : remove and replace......
: repair .................
: frequency ..............

**Comments:**

**Instructions:**

1. If vendor supplied rebuilt injectors are used, please note.

**System: Heating and Ventilation**

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair

1. Blower motors : remove and replace......
: rebuild.................
: frequency ..............

2. Heater core : remove and replace......
: rebuild.................
: frequency ..............

**Comments:**

**Instructions**

**System: Steering**

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair

1. Power steering pump : remove and replace......
: rebuild.................
: frequency ..............

2. Upper gear box : remove and replace......
: rebuild.................
: frequency ..............

3. Lower gear box : remove and replace......
: rebuild.................
: frequency ..............

**Comments:**

**Instructions:**

1. Running repair includes alignments, adjustments and trouble shooting.

**System: Suspension**

**Work Activity:**

Running repair : man-hours..............
per bus per year

Unit repair

1. Misc. components : man-hours..............
per bus per year

**Comments:**

**Instructions:**

1. Include the rebuild of air bellows, radius rods, sway bars, etc. in miscellaneous repair.

System: Wheels and Tires

**Work Activity:**

1. Running repair : man-hours.............. per bus per year

**Comments:**

**Instructions:**

1. Determine the role of tire suppliers in tire repair and replacement.

## STANDARD GLOSSARY OF TERMS

Advanced Design Bus (ADB) - Generic description for that class of buses comprised of the GMC RTS and Grumman Flxible 870.

Air Conditioning - Vehicle system that cools vehicle interior during warm weather. It includes the compressor, condensor assembly, evaporator assembly, receiver, dryer, filters, piping, and cables.

Air System - Vehicle system that includes compressor, air pipe and tubing, control cylinders, shift cylinders, air tanks, air governors, air gauges, safety valve, door interlocks, brake valves, quick release valves, brake diaphragms, air pressure regulator valve, air line shut-off valve and door regulator valve.

A/C Compressor - Component used in the air conditioning system to compress freon so maximum use may be made of that gas's heat absorption properties.

Accident - Mishap resulting in damage to the vehicle.

Air Compressor - Used to provide compressed air for use in the braking, door, windshield wiping, and suspension systems.

AMG - A. M. General Corporation.

Apprentice Mechanic - Beginning mechanic with sufficient basic skills to perform routine maintenance tasks. Often works with or under direction of journeyman or master mechanic.

Base Service - Periods of service during off-peak hours.

Body - Vehicle system including bumper assembly, exterior paneling, mirrors, windshield and frame, stanchions, seats, floor, floor covering, steps, doors, chimes or buzzer, windshield wipers, interior panels, and glass.

Body Shop - Group responsible for all major vehicle body repairs and painting. Work may include signage, panel replacement, glass replacement, upholstery repair, and structural repair. Running repair may perform minor body repairs such as mirror replacement, simple panel replacement, and touch-up painting.

Braking System - Vehicle system used to stop the vehicle. Brake components include drums, shoes, lining, seals, spiders, cams and slack adjustments.

Bumper - Metal or composition protective devices mounted to the front and rear of vehicles.

Chassis Wash - Activity associated with high pressure or steam cleaning of bus engine compartments and undercarraiges.

Component Rebuild - Group responsible for rebuilding all major and minor components including engines, transmissions, generators, starters, compessors, controls, steering components, radiators, air motors, and hardware. Work includes machining, cleaning, and welding.

Cooling System - Vehicle system that includes radiator, thermostat and housing, water pump, fan, fan torus, vernatherm, surge tank, oil cooler, hoses and temperature gauges.

Crown - Crown Coach Corporation.

Destination Sign - Electronic or curtain type signs used to inform patron of bus route and destination.

Differential - An arrangement of gears in the rear axle assembly which permits the driving axles to rotate at different speeds. It includes gears, bearings, carrier and seals.

Electrical System - Vehicle system that includes generator/alternator, regulator, battery, starter, lighting system, control switches, solenoids, horn, wiring, and cabling.

Engine Assembly - Vehicle assembly that includes engine cradle, blower, flywheel, engine governor, flywheel housing, crankshaft, oil pump, valve covers, heads and valves, injectors, timing gears, camshaft and valve mechanism, oil gauges, oil filters, oil pan and damper.

Engine Blower - A unit mounted to engine in order to force air into and exhaust gases out of the compustion chamber.

Engine Rebuild -The process of completely rebuilding a worn or defective engine, includes complete teardown, cleaning, rebuilding of engine components (heads, blower, water pump, etc.) machine work, assembling and testing.

Engine R & R - Includes removal of defective engine and replacement with new or rebuilt unit. In most buses the complete power plant is removed for easier access to engine.

Farebox - A container for safe keeping of fares collected during service. May be equipped for passenger counting.

Flyer - Flyer Industries Limited.

FLX - Flxible Corporation.

Fuel System - Vehicle system that includes fuel pump, fuel lines, filters, fuel hose-lines and fuel tank.

GFC - Grumman Flxible Corporation.

GFC 870 - Advanced design bus produced by Grumman Flxible Corporation.

GMC - General Motors Corporation.

Heating/Ventilation System - Vehicle that provides heat and ventilation to the interior. It includes heating units, blowers and blower motors, water modulation valve and heater related cables and wiring.

Heavy Repair - Responsible for repairs that require considerable time to facilitate, such as power plant change-outs or complete suspension overhauls.

Hostler - A maintenance person who shuttles buses to and from the service and clean area and is responsible for fueling and servicing buses.

In-Frame Overhaul - A partial overhaul of engine while in bus, usually includes heads, blower, piston, sleeve, and bearing replacement.

Inspection - The performance of preventative maintenance and safety checks includes the following:

- Statutory - A check of safety items required by the state or local authority.
- Minor - Includes items from safety inspection plus additional systems inspection and lubrication.
- Major - Includes elements of safety and minor inspection in addition to in-depth servicing of vehicle systems including engine tune-up.
- Other - Any scheduled P/M work such as seasonal servicing of HVAC or air system.

Interior Clean - A scheduled thorough interior cleaning of buses that usually occurs on day-shift and includes: trash removal, window washing, cleaning seats, mopping floors, and dusting.

Journeyman Mechanic - A mechanic with sufficient skills to perform most maintenance tasks with very little supervision.

M.A.N. - M.A.N. Truck and Bus Corporation.

Master Mechanic - Skilled in all phases of the craft. Often times directs repairs of journeyman or apprentice mechanics.

MCI - Motor Coach Industries.

New Look - A term used for model of bus produced priorto 1979 by GMC and Flxible.

Neoplan - Neoplan USA Corporation.

Operating Speed - Average speed of a vehicle over a fixed route while in revenue service. A simple calculation is to divide revenue miles by revenue hours.

Parking Brake - Vehicle component used to hold a vehicle stationary when parked.

Peak Hours - The daily periods of highest demand on the transit systems service.

Phantom - Model of transit bus manufactured by Gillig Corporation.

Powerplant - Combination of engine and transmission with necessary accessories used to power vehicle.

Radio - Two way radio used for communication between individual buses and base.

Remove and Replace - Removal of a defective component or assembly and replacment with a serviceable unit, including testing.

Revenue Hours - Total hours a vehicle is in actual service carrying passengers not including dead head or layover time.

Revenue Miles - Total miles vehicle travels while in service not including dead head miles.

Road Call - Any reported in service problem or delay resulting from a maintenance related mechanical or electrical malfunction.

RTS - Advanced design bus produced by General Motors Corporation.

Running Repair - A function of maintenance that is responsible for the day-to-day repair of vehicles. Repairs are usually limited to repairs requiring less than eight clock hours to complete. Running Repair may not be separated from Heavy Repair at smaller operations.

Service and Clean - Group responsible for fueling, washing, cleaning interiors, topping off fluids, and chassis washing.

Spares - Vehicles not required for service during peak service demands.

Specialist - Refers to skilled workers who perform non-direct related bus repair activities, including: welding, machining, and electronic repair.

Steering System - Vehicle system that includes steering wheel, steering column, steering box, drag links, tie rods, tie rod ends and power steering pump, if included.

Subfleet Profile - Identifies characteristics of a group of vehicles. Groups are usually of the same make and model. Profile contains information relative to type of powerplant, farebox, radio, wheelchair lift, destination signage, and bumpers.

Suburban Bus - A single door bus with high back seats used for express service.

Suspension System - Vehicle system that includes bellows, leveling valves, shock absorbers, radius bars, lateral bars, and stabilizer.

Transit Bus - A two-door bus with high back seats used for transit service.

Transmission - An assembly of gears and/or clutches by which engine power is transmitted to the drive axles.

Turbocharger - Serves same basic function as engine blower.

Unit Shop - Synonymous with component rebuild shop.

VH, VS, V-730 Series Transmissions - Designations for Allison, angled or V-drive, transmissions commonly used in transit buses. Output power shaft of transmission is set at an angle from engine imput power shaft which allows for transverse mounting of engine in rear of bus.

Vehicle Inventory - A list that minimally identifies each vehicle by identification number, make, model, year of manufacture and serial number. May include powerplant, seating, and basic specification information as well.

Wheel Assembly - Vehicle assembly that includes hubs, bearings and seals, wheel, and tires.

Wheelchair Lift Assembly - A level change mechanism used for loading and unloading wheelchair bound patrons. It includes reservoir and filter, pump, hydraulic lines, control box, cylinders, sensitive edges, platform, riser assembly, console and electrical parts.