Work Standards: Their Use and Development Using a Maintenance Management Information System

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Work standards are a tool that maintenance managers can apply in annual planning and budgeting, daily planning, scheduling, and work control. Frequently, maintenance managers rely on inherited standards, adapt published standards, or do without. In such cases, they are overlooking a resource, their Maintenance Management Information System (MMIS), which can be used to develop preliminary work standards to aid in planning, scheduling, and controlling maintenance resources. Research for this paper was conducted at a major transit system as part of an overall management study of the organization. A methodology using MMIS records to establish preliminary work standards for division-performed maintenance is presented in the following sections. Preliminary standards for the organization are recommended and the analytical results are interpreted.

The management of maintenance activities and the allocation of maintenance resources to activities represent a long-term challenge to fleet managers. Basic sets of objectives normally underlie the day-to-day management review of maintenance performance, costs, and budgets. Each of these motivators causes managers to examine functions and cost elements in different ways. The typical underlying objectives that motivate maintenance managers are

- The need to manage and control costs (controlling);
- The need to estimate and budget costs with confidence (planning); and
- The need to invest in staff, systems, and facilities to improve service or cost (investing).

The application of work standards in the management of maintenance activities is not frequently encountered in the transit industry. Maintenance managers frequently look for industry guidelines, hoping to discover standards applicable to their fleets. Recent research efforts have provided recommended time standards for hundreds of maintenance activities, as well as methods for establishing time standards (*1,2*).

Earlier emphasis on life-cycle cost vehicle procurements brought forward many of the shortfalls of using repair time standards. However, the life-cycle cost debate did result in the documentation of work standards (*3*). Although the standards proved inconsequential in determining life-cycle cost, because of the dominance of fuel efficiency, many managers recognized the value of standards in controlling, planning, and investing in maintenance activities.

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THE ROLE OF STANDARDS IN MAINTENANCE MANAGEMENT

Work standards should be an integral part of the maintenance management process, as shown in Figure 1. The requirements placed on maintenance managers are driven by revenue service vehicle needs, nonrevenue vehicle needs, remanufactured component use rates, and facility needs. These requirements influence both long-range (annual) and short-range (daily and weekly) planning. Daily and weekly planning influences work control at operating divisions and central maintenance facilities. Work control provides the documentation necessary to support special studies to improve reliability, increase efficiency, and improve performance. Maintenance managers should use work standards to fulfill each of these responsibilities. By using work standards in annual planning, daily and weekly planning, work control, and special studies, managers can increase productivity (*4*). Standards are valuable for more than just evaluating employee performance.

Annual Planning

In the annual maintenance planning process, work standards allow managers to determine production plans and rates at both central maintenance facilities and operating facilities. Production plans define resource budgets by determining labor, material, equipment, and facility needs to satisfy production needs. For example, if service requirements, combined with capital and operating cost constraints, call for the rehabilitation of 100 buses per year, then work standards will determine the total labor requirement, in terms of applied labor hours. The required applied labor hours are then converted to staffing levels based on attendance rates, labor agreement terms and conditions, and other factors.

Maintenance resources are finite and must be allocated to achieve high levels of cost-effectiveness. The allocation process balances the use of private enterprise with inhouse capabilities to meet production targets. Work standards in this context can be applied to justify the purchase of maintenance services or the allocation of resources to a maintenance activity.

Daily Planning

Work standards are also an integral part of daily maintenance planning. Without standards, managers may be unable to

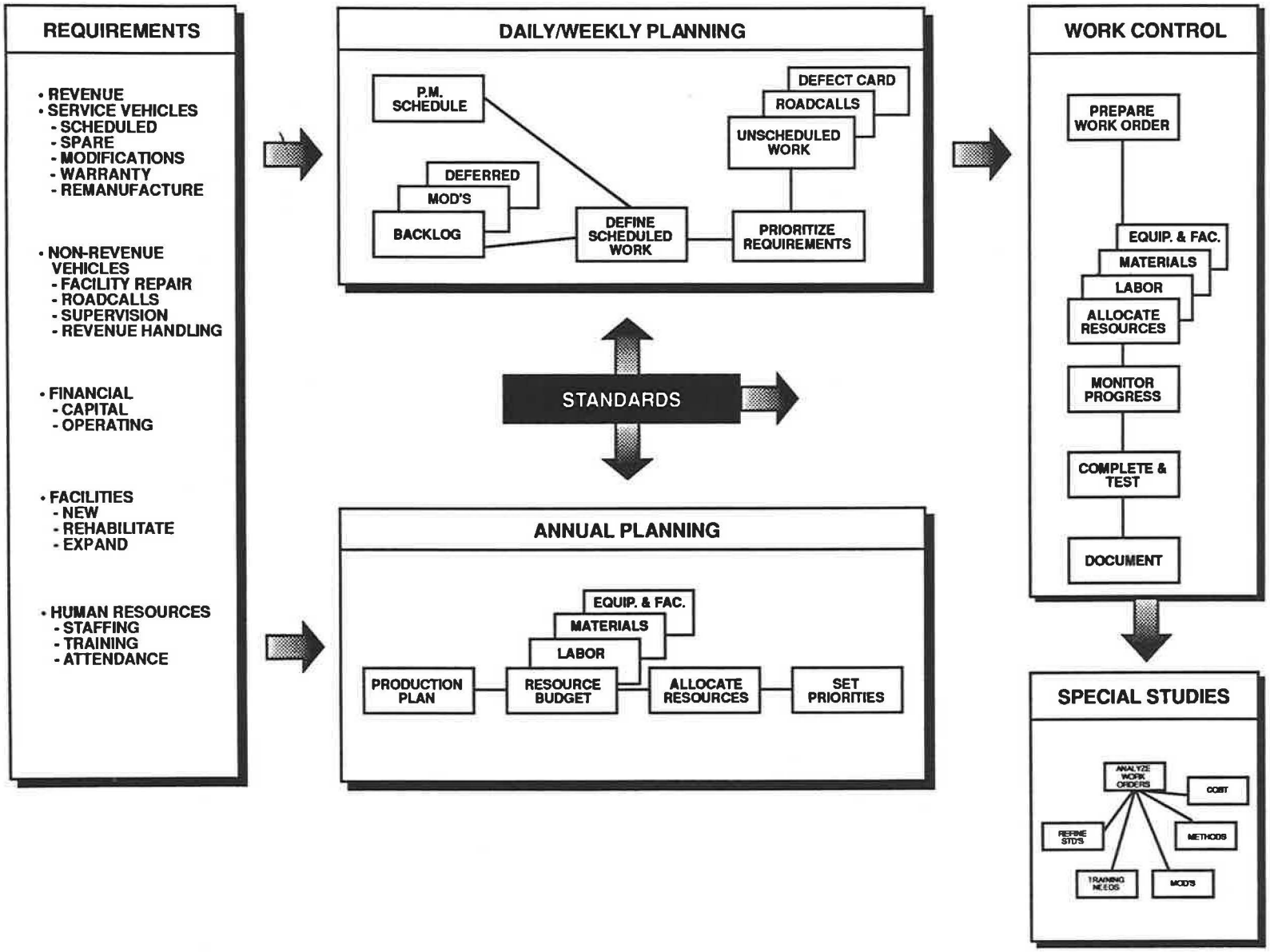


FIGURE 1 Standards influence key aspects of the maintenance process.

maximize workforce use, and overall productivity will decline (*5*). When this occurs, the unaccounted time (time not reported on work orders or time cards) exceeds expected levels (*6*). At any maintenance facility, managers must combine preventive maintenance schedules with the maintenance backlog associated with in-service failures, deferred repairs, and vehicle modifications resulting from warranty and engineering studies. Standards define the daily and weekly maintenance demand both for inspection and regular maintenance activities.

Knowing the total maintenance demand, managers make work schedules by balancing preventive maintenance inspections and the repair backlog. Complicating the scheduling process are unscheduled repairs generated by roadcalls and defect cards. Although some transit systems have dedicated roadcall staff, others use shop mechanics on an as-needed basis, resulting in significant disruption to the scheduled work flow. Roadcall resolution is a high-priority maintenance activity, because service disruptions must be minimized.

Defect cards come from two sources. Operators typically complete defect cards at the end of scheduled runs. Operator defect cards must be screened daily by managers to determine the priority of these repairs and to determine resource requirements using work standards. Defects and repair needs are also identified during preventive maintenance inspections. Depending on the work standard used for the inspection, minor defects can be repaired during the inspection. Major repairs, such as brake relines, are typically identified for subsequent repair scheduling.

Work Control

Once a prioritized schedule of work is complete, work orders are assigned to specific maintenance staff, thereby allocating resources to single activities. Work standards can be used to determine which staff members are available for unscheduled repairs. The objective of the manager is to combine assignments to reach the full utilization of staff.

In the example shown in Figure 2, four mechanics are assigned to five repair tasks. Mechanics Smith and Roberts are first assigned to a transmission change (TRN–CHG), which has a work standard of 8 hr with 1.5 staff. To fill Smith's time, a brake reline is assigned, leaving only 30 min of unassigned time. This time can be used for technical problems that may occur in the transmission change, or for unscheduled repairs.

Mechanics Allen and Jones clearly have substantial amounts of unassigned time that can be used for unscheduled repairs. Without using work standards to develop daily work plans, a manager may not be able to determine staff availability for unscheduled repairs or the maintenance backlog.

Work standards are also a valuable tool for monitoring repairs in progress. Although work standards reflect typical times for component repairs, repairs generally progress through three phases: troubleshooting and diagnostics, repair and corrective action, and testing.

In the sample daily work plan (Figure 2), mechanic Allen has been assigned to an engine repair. The supervisor should recognize that troubleshooting an engine takes a variable amount of time. However, based on repair experience and the availability of repair time data, the supervisor may know approximately when the diagnostic phase will be complete. Likewise, the supervisor should know the approximate durations of engine repairs and testing. Using informal standards for diagnostics, repair, and testing, a supervisor can review the progress of mechanic Allen to determine whether more or less time (a maintenance resource) is needed for the repair action.

Special Studies

The completion of repairs and their documentation is critical to the ongoing use and evolution of work standards. The implementation of Maintenance Management Information Systems (MMISs) to compile data on maintenance activities provides managers with the information to increase productivity and efficiency (*7*).

The analysis of work orders can yield valuable information regarding the validity of existing work standards. Significant deviations from established work standards by individual staff

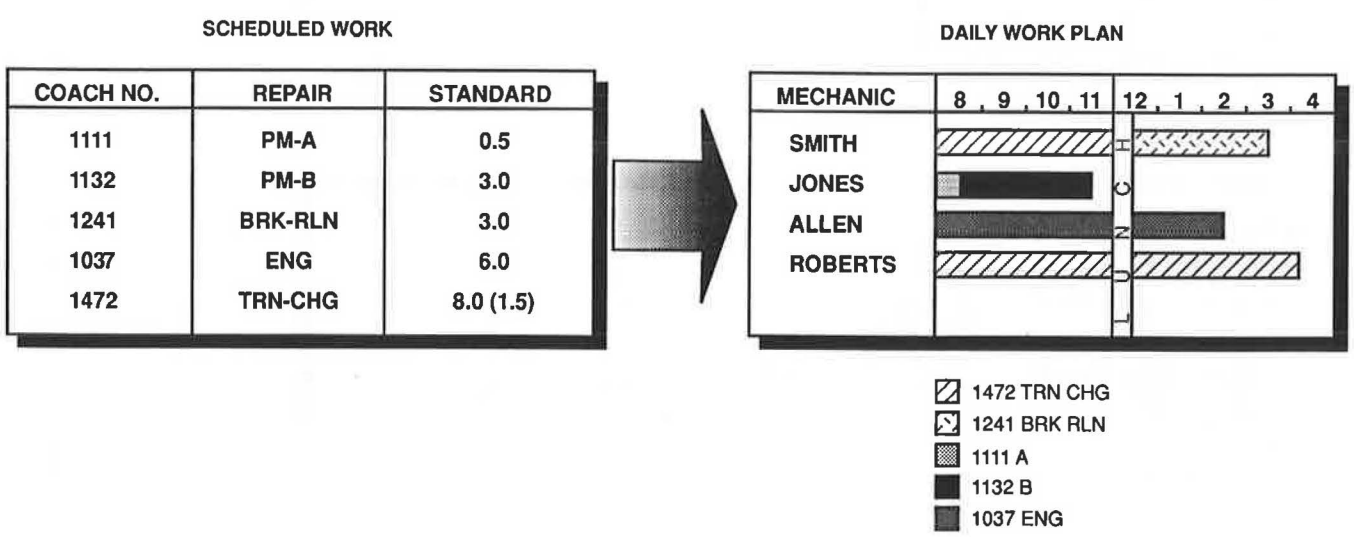


FIGURE 2 Application of standards in work planning.

members can indicate training needs. By matching frequencies and times for specific repairs, it is possible to identify component modifications that would improve reliability and reduce repair costs. Likewise, a need for improved methods to reduce repair times, or to narrow the distribution of repair times, can be identified. Finally, combining work standards with cost data to determine typical repair costs or annual repair costs can be used to evaluate the use of private enterprise for specific repairs (*8*).

RESEARCH OBJECTIVE AND APPROACH

Although the value of standards has been demonstrated, some managers have not established work standards or have not recently evaluated current work standards. MMISs contain the resources available to managers to begin developing or revising work standards.

The research effort presented here was part of a management performance evaluation by a major transit operator with a fleet of over 700 vehicles. The objectives of the research were as follows:

- Identify components accounting for significant consumption maintenance of labor resources,
- Develop tools to increase workforce productivity given known staff shortages, and
- Provide guidelines for daily and annual maintenance planning.

Maintenance data were downloaded from the MMIS to compute major component group costs and total annual costs. Repair times per component by activity were also calculated using this data base for component groups with sufficient and reliable data.

To ensure a sufficient number of observations across all repair types, a large sample of work orders was used. Over 42,000 work order entries, covering the period between January and April 1988, were taken from the MMIS to form the data base for the investigation.

To ensure that all data were included for each repair, individual work orders and line items within single work orders were examined. For each unique object code (component) and activity code (repair type) pair, line item labor hours were aggregated to produce a total labor hour data point. The data base was also reviewed for sequential work order numbers with identical object/activity code pairs to screen out multiple work orders for a single repair. The structure of the data base did not allow for the discrete analysis of specific components, such as repair hours for 6V92 engines. Further research, using the methodology provided and including major component identification numbers, would be beneficial. The data required for such an analysis was not included in this data base.

Within the MMIS, maintenance activities were documented using many object codes and activity codes. Object codes describe individual components, subcomponents, and individual parts, whereas activity codes describe the type of repair conducted. The MMIS and its associated work order system use 395 object codes and 17 activity codes for revenue vehicle repairs. This array produces 6,715 object/activity code pairs. Analysis of individual object/activity code pairs would generate relatively meaningless information for managers regarding cost containment, improved work force productivity, and reliability improvement. To effectively manage maintenance resources, managers and supervisors should not be inundated with hundreds of work standards. To be effective, managers use performance guidelines in combination with knowledge of their workforce capabilities and the complexities of maintenance activities.

To identify feasible opportunities for managers to improve maintenance performance, it was necessary to aggregate object codes according to component types or systems, and to aggregate activity codes according to similar types of activities. Object code groups, presented in Table 1, were developed from the object codes currently in the MMIS. A total of 26 object code groups was developed for subsequent analysis.

Activities were also grouped, producing 12 activity codes for analysis, as presented in Table 2. Similar types of MMIS repair activities that were anticipated to have comparable labor hour requirements were grouped together. The aggregated codes provided specific information regarding division and central maintenance performance.

The reorganization of terms could produce up to 312 object/activity code pairs. Although more manageable than 6,715 code pairs, these repair descriptions may still be too numerous for managers to effectively apply as time standards. However, the 26 object codes and 12 activity codes allow managers to understand which components and repairs consume the most labor hours and cost. Repair time distributions were developed by object code, and preliminary work standards were developed for the top 10 components.

PRELIMINARY WORK STANDARDS

The distribution of labor hours across major component groups focuses attention on specific components where more efficient procedures could improve maintenance productivity. The average repair times derived from the investigation can be used to improve the scheduling of planned or unplanned repairs. The methodology and results represent a first step toward establishing work standards. Use of the average repair times can assist in improving workforce utilization, reduce unaccounted time, identify mechanics' performance and training needs, and provide managers with a better understanding of where maintenance resources are applied.

The average repair hour figures provide a preliminary work standard time that can be used in time planning for maintenance activities in the division facilities. The standard deviation provides a measuring device reflecting the range of observed repair times about the average; because of aggregation of both activity codes and object codes, high deviations were expected. For example, different types of engines (such as 6V92 and 8V71) will cause clusters of observations at different time periods. The average repair time would be between the two clusters, and the deviation would include the two clusters.

The inclusion of several activities into a single activity code group was also expected to produce high deviations. For example, inspecting a bad order coach (IBO) should take more time than checking fluids (CHK), yet both activities are within the inspection activity code group.

The broad range of scheduled and unscheduled repairs occurring at the divisions during the analysis period, combined with

TABLE 1 MMIS OBJECT CODE REGROUPING

MMIS Object Code Range	Analysis Object Code Group Description
0100 to 0192	Front Axle
0200 to 0292	Rear Axle
0400 to 0450	Brake System
0500	Clutch
0600 to 0692	Cooling System
0700 to 0783	Electrical System
0800 to 0897	Engine
1100 to 1120	Frame
1200 to 1292	Fuel System
1400 to 1492	Suspension
1600 to 1692	Steering
1700 to 1792	Transmission
1800 to 1892	Drive Train
1900 to 1940	Wheels
2400 to 2437	Body – Exterior
2438 to 2492	Body – Interior
2600 to 2692	Air Conditioning
3000 to 3091	Air Group
3200	Flex Line
3500	Auxiliary Equipment
3540	PA System
5300 to 5301	Destination Signs
5400 to 5401	Farebox
5500 to 5515	Wheelchair Lift
5600 to 5603	Transfer Machine
9000	Preventive Maintenance Inspections

the varying working conditions, further influenced average repair times and deviations. At the time of the research, two maintenance facilities were undergoing significant reconstruction, which disrupted normal repair activities.

Although these factors will produce higher deviations in repair times than figures from a disaggregate analysis, the average times can still be used as a first step and tool for planning and controlling maintenance activities and achieving productivity improvements. To provide this tool, the average times for each phase of a repair (troubleshooting and diagnostics, repair and corrective action, and testing) were combined, resulting in a repair time standard for component repairs. The application of such a preliminary time standard should also incorporate the experience and judgment of individual maintenance supervisors.

Research efforts in transit maintenance have suggested that repair time distributions conform to gamma distributions (*1*). Although the research conducted for this paper did not address this hypothesis, the repair time distribution did resemble a gamma distribution. Further research in this area would be beneficial to further development of repair time standards.

FINDINGS

The distribution of labor hours by major component groups identified 10 groups that accounted for over 85 percent of the labor hours in the divisions, as presented in Table 3. The development of preliminary work standards for these component groups was the focus of the research. The preliminary work standards represent a first step toward providing managers with a tool to increase the control of labor resources. The intent of the research was not to develop absolute standards, but rather to examine repair times for the 10 component groups and establish opportunities for increased productivity. Discussions were conducted with maintenance managers to explain the distribution of repair times and to identify feasible opportunities for productivity improvements.

Preventive Maintenance Inspections

Preventive maintenance inspections account for 28 percent of the labor hours in the divisions, as presented in Table 3.

TABLE 2 MMIS ACTIVITY CODES

MMIS Activity Code	Description	MMIS Activity Code	Description
ADJ	Adjust	OTH	Other
ASM	Assemble	PNT	Prepare and Paint
CHG	Change	RBO	Running B.O.
CHK	Check	RCL	Roadcall
CLN	Clean	REQ	Requisition
CRG	Charge	RFC	Reface
DIS	Disassemble	RLN	Reline
IBO	Inspection B.O.	RMN	Remanufacture
INS	Inspect	RMV	Remove
IST	Install	ROT	Rotate
LUB	Lubricate	RPR	Repair
MAG	Magnaflux	RTQ	Re-Torque
MCH	Machine	SFI	Safety Inspection
MJI	Major Inspection	SOV	Semi-Overhaul
MNI	Minor Inspection	SRV	Service
NOR	Normalize	STM	Steam Clean
TST	Test	WLD	Weld

Reorganization of Activity Codes for Analysis

Inspection	=	IBO, INS, CHK, TST, CLN, SRV, STM, DIS
Light Repair	=	ADJ, CRG, ROT, RTQ, LUB
Heavy Repair	=	RLN, RBO, RPR
Remove-n-Replace	=	CHG, IST, RMV
Rebuild	=	MAG, MCH, NOR, ASM, WLD, RFC
Body	=	PNT, REQ, OTH
Safety Inspection	=	SFI
Roadcall	=	RCL
Minor Inspection	=	MNI
Major Inspection	=	MJI
Semi-Overhaul	=	SOV
Remanufacture	=	RMN

TABLE 3 DIVISION MAINTENANCE LABOR-HOUR DISTRIBUTION OBJECT CODE RANKING BY TOTAL HOURS

Major Component Group	Percent of Total Hours	Cumulative %
1. Preventive Maintenance Inspections	28.0	28.0
2. Electrical System	12.0	40.0
3. Brake System	8.6	48.6
4. Body Exterior	7.5	56.1
5. Wheelchair Lift	6.7	62.8
6. Engine	6.6	69.4
7. Air Group	4.7	74.1
8. Suspension	4.7	78.8
9. Transmission	3.6	82.4
10. Cooling System	3.5	85.9

Within this activity, safety inspections clearly dominate in frequency of occurrence, as shown in Figure 3. However, major inspections account for over half of all inspection labor hours. An examination of the labor hour distribution reveals that

- Safety inspections are typically completed in 0.32 hr.
- The average minor inspection time is 1.28 hr. The small standard deviation reflects the narrow distribution of observed times. Minor inspections account for 19 percent of all inspection hours.
- An average time of 2.98 hr was calculated for major inspections. The distribution of inspection times indicates major inspections' being performed from between 1.5 and 2.0 hr to between 4.0 and 4.5 hr.

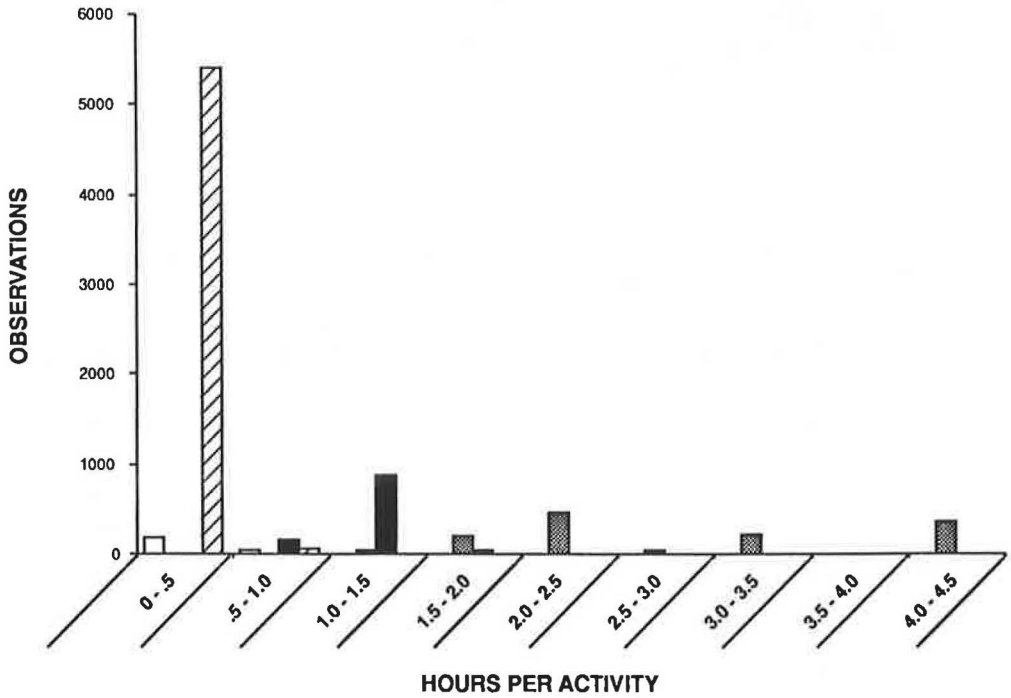
Safety inspection work standards of 0.25 hr and minor inspection work standards of 1.25 hr appear to be appropriate and should be vigorously applied by maintenance managers. The performance of major inspections should be closely examined through direct observation to explain the broad distribution of observed times. The appropriateness of a 3-hr standard based on the average inspection time cannot be determined at this time.

Electrical System

Electrical system repairs are a major consumer of maintenance resources from a labor-hour perspective. The distributions of repair times and average repair times shown in Figure 4 begin to explain the high cost of electrical system maintenance.

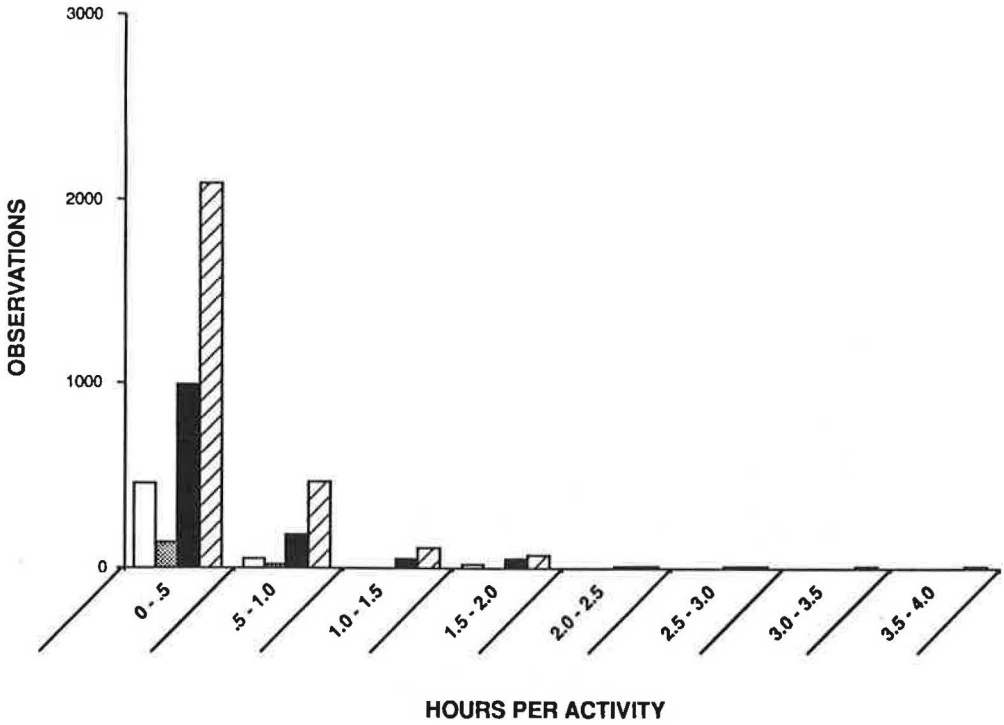
- Remove-and-replace activities account for over 60 percent of observed electrical system repairs and have an average time of 0.57 hr. However, the distribution is broad (reflected by the high standard deviations), as expected, because of the variety of electrical components included in the consolidated object code.
- Heavy repair activities have an average time of 0.56 hr and a high relative standard deviation. This activity accounts for almost 30 percent of the observed electrical system repair times.
- The average light repair time is 0.33 hr, principally reflecting battery charging and cleaning of battery trays. Light repairs account for less than 5 percent of all electrical system repair hours, therefore representing only limited opportunities for improving maintenance performance.
- Inspection of electrical systems accounts for the fewest number of observations and less than 5 percent of the hours. Given the difficulty of diagnosing electrical system failures, the low frequency of occurrence indicates that not enough troubleshooting is being done. This situation would contribute to the high number of remove-and-replace observations.

The dominance of remove-and-replace and heavy repair activities, accounting for approximately 90 percent of all electrical system repair labor, indicates that significant manage-



INSPECTION	MAJOR	MINOR	SAFETY
AVERAGE HOURS .44	AVERAGE HOURS 2.98	AVERAGE HOURS 1.28	AVERAGE HOURS .32
STANDARD DEVIATION HOURS .30	STANDARD DEVIATION HOURS 1.06	STANDARD DEVIATION HOURS .22	STANDARD DEVIATION HOURS .15

FIGURE 3 Preventive maintenance inspections (Object Code 9000).



INSPECTION	LIGHT REPAIR	HEAVY REPAIR	REMOVE-N-REPLACE
AVERAGE HOURS .40	AVERAGE HOURS .33	AVERAGE HOURS .56	AVERAGE HOURS .57
STANDARD DEVIATION HOURS .39	STANDARD DEVIATION HOURS .20	STANDARD DEVIATION HOURS .51	STANDARD DEVIATION HOURS .60

FIGURE 4 Electrical system (Object Codes 0700–0784).

ment and supervisory focus should be placed on this aspect of electrical system repair.

In terms of preliminary work standards, a time of 1 hr should be anticipated for preliminary diagnostics (inspection) and corrective action. A more rigorous standard of 0.5 hr for remove-and-replace activities could be adopted, particularly if a policy is adopted to troubleshoot and repair electrical components at the central maintenance facility. Adopting such a policy would increase the availability of division mechanics and potentially improve the quality of repairs, because skilled electrical mechanics would perform repairs in a more controlled environment.

Brake System

Average brake system repair times, anticipated to be 4 to 5 hr, are noticeably lower at a total of 2.78 hr for remove-and-replace plus heavy repair, as shown in Figure 5.

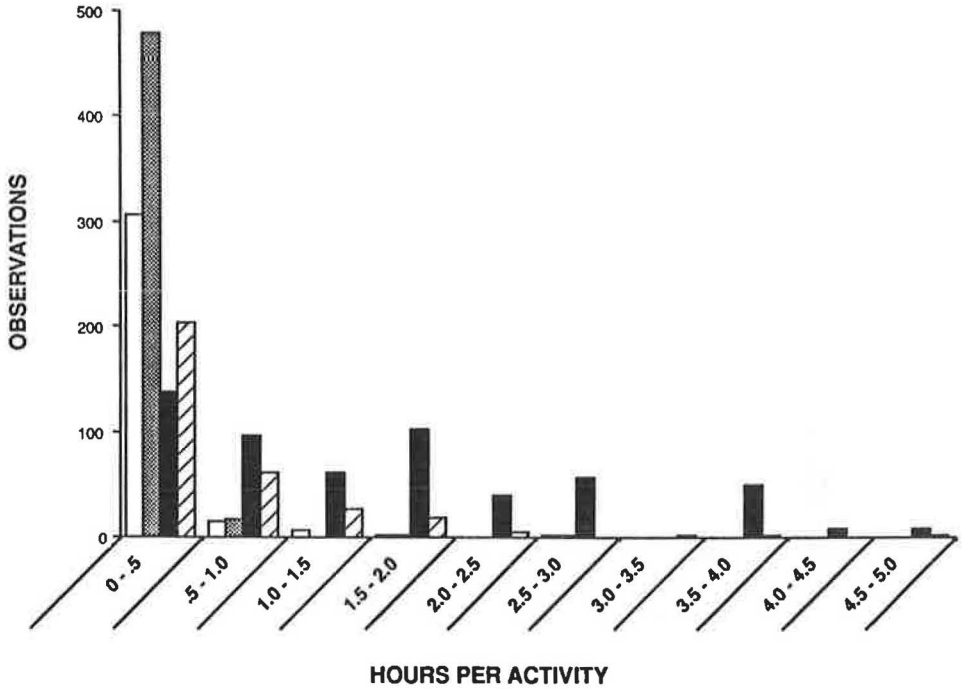
- For heavy repairs, times ranged between 0.25 and 5 hr. The low average time of 1.86 hr coupled with a high standard deviation of 1.39 hr indicates that the average time cannot be used as a preliminary standard.
- The average light repairs time of 0.26 hr plus the average inspection time of 0.36 hr provides a reasonable standard of 40 min for brake adjustment, assuming that both wheels on the same axle are done simultaneously.

The average brake system repair hour findings are influenced by reliability problems with automatic slack adjusters. The reliability of this component is cited by managers throughout the industry as a problem. Slack adjusters are contributing to the broad distribution of heavy repair times. However, they do not completely explain the variation, particularly with the few observations over 4 hr.

Body Exterior

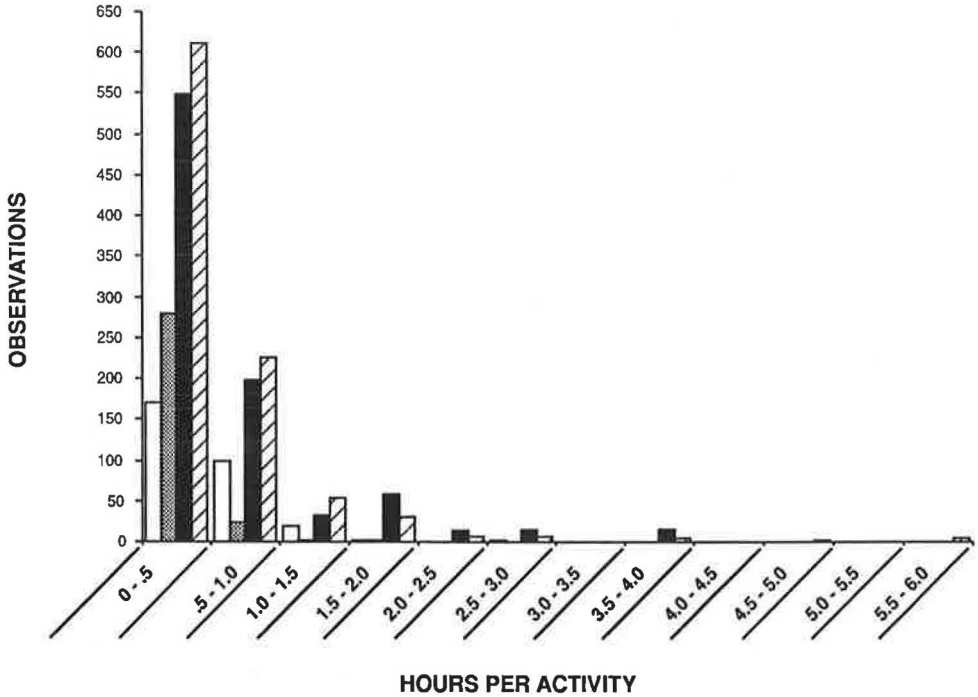
The distribution of body exterior repair times shown in Figure 6 reveals unexpected characteristics:

- The body activity code for prepare and paint occurs infrequently, suggesting that this repair is not conducted at the divisions, even though some facilities have the capability and staff.
- Heavy repairs are the second most frequent activity, accounting for approximately 43 percent of all body exterior repair hours. The average repair time of 1 hr and the large deviation (1.4 hr) indicate that complex repairs are occurring at the divisions.



INSPECTION	LIGHT REPAIR	HEAVY REPAIR	REMOVE-N-REPLACE
AVERAGE HOURS .36	AVERAGE HOURS .26	AVERAGE HOURS 1.86	AVERAGE HOURS .92
STANDARD DEVIATION HOURS .31	STANDARD DEVIATION HOURS .25	STANDARD DEVIATION HOURS 1.39	STANDARD DEVIATION HOURS 1.23

FIGURE 5 Brake system (Object Codes 0400–0450).



INSPECTION	LIGHT REPAIR	HEAVY REPAIR	REMOVE-N-REPLACE
AVERAGE HOURS .66	AVERAGE HOURS .38	AVERAGE HOURS .99	AVERAGE HOURS .70
STANDARD DEVIATION HOURS .54	STANDARD DEVIATION HOURS .31	STANDARD DEVIATION HOURS 1.40	STANDARD DEVIATION HOURS .70

FIGURE 6 Body exterior (Object Codes 2400–2437).

• Remove-and-replace repairs account for more than 35 percent of body repair hours, the second largest contributor. This activity is more in line with the functions of the divisions. The average repair time (0.7 hr) and the deviation (0.7 hr) appear reasonable, given the broad spectrum of candidate repairs (from changing light bulbs to replacing bumpers and skirt panels).

• Light repairs account for slightly more than 5 percent of all body repair hours. The low frequency of occurrence, total repair hours, and small average repair times of 0.38 hr indicate that improved productivity in this function would be difficult to achieve.

• Body inspection activity, while accounting for 10 percent of the body repair hours, can be improved on given an average inspection time of 0.66 hr or 40 min. The inspection hour figure is being influenced by the inspection for structural cracks.

For work scheduling and repair planning purposes, a preliminary standard body maintenance time of 1.5 hr should be used. This standard includes light or heavy repair times combined with inspection and remove-and-replace times.

Wheelchair-Lift Repairs

Wheelchair-lift equipment poses many difficulties for maintenance managers throughout the industry. Mechanical complications and low tolerances in clearance cause frequent problems with wheelchair-lift service and maintenance.

This investigation identified a high frequency of inspections in the 0.5- to 1-hr range, more than double the repair activity codes shown in Figure 7. Inspections occur almost four times more frequently than all other activities, reflecting the difficulties in detecting and resolving lift defects. Likewise, the large standard deviation associated with each average repair time further supports the difficulty of wheelchair-lift repairs.

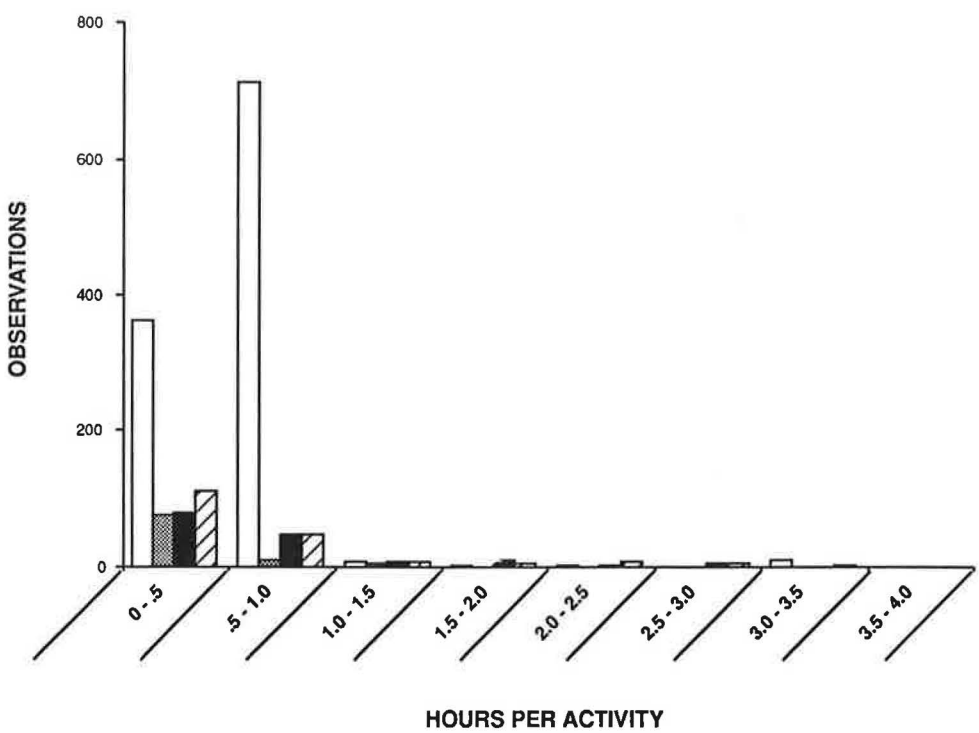
A preliminary work standard of 1.5 hr should be used for planning wheelchair repairs. This standard includes sufficient time for inspection and repair.

Engine

The investigation of engine repairs conducted at the divisions was limited to light and heavy repairs, inspections, and remove-and-replace activities. The analysis included all object codes between 0800 and 0897. The broad range of object codes was expected to result in large standard deviations for each repair activity. The distribution of repairs, shown in Figure 8, confirms these expectations. However, the deviation is not as great as originally expected.

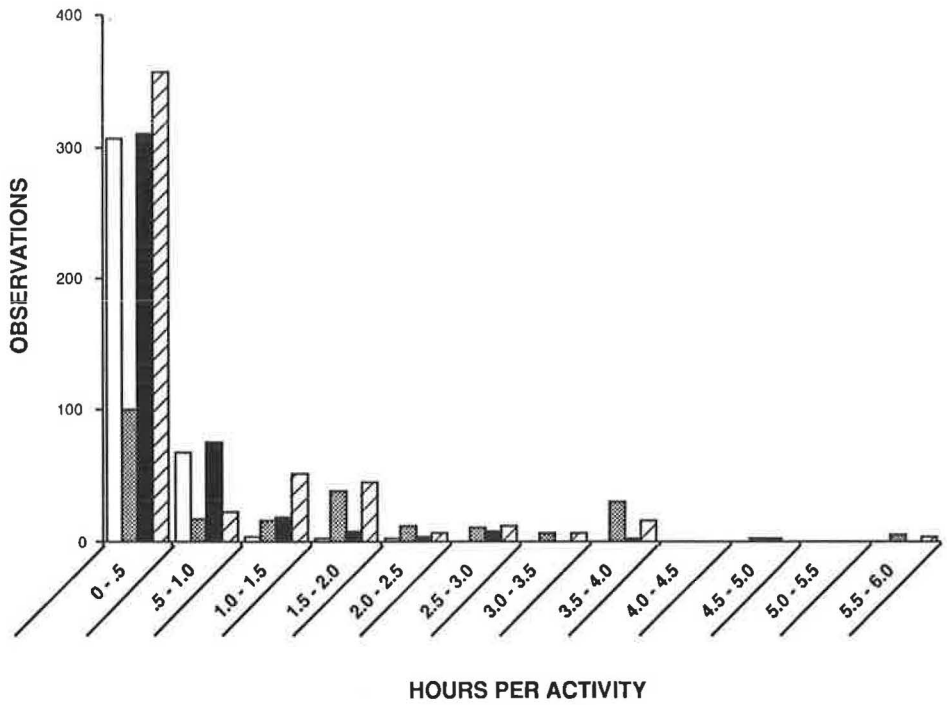
• Inspection times are relatively uniform at an average of a half-hour. This observed average should be sufficient to define specific repair requirements and to determine whether a coach should be sent to central maintenance.

• Light repairs occur the least frequently yet have the highest average repair time. The average time is influenced by



INSPECTION	LIGHT REPAIR	HEAVY REPAIR	REMOVE-N-REPLACE
AVERAGE HOURS .62	AVERAGE HOURS .41	AVERAGE HOURS .99	AVERAGE HOURS .84
STANDARD DEVIATION HOURS .36	STANDARD DEVIATION HOURS .30	STANDARD DEVIATION HOURS .92	STANDARD DEVIATION HOURS .91

FIGURE 7 Wheelchair lift (Object Codes 5500–5515).



INSPECTION		LIGHT REPAIR		HEAVY REPAIR		REMOVE-N-REPLACE	
AVERAGE HOURS	.47	AVERAGE HOURS	1.78	AVERAGE HOURS	.65	AVERAGE HOURS	.98
STANDARD DEVIATION HOURS	.33	STANDARD DEVIATION HOURS	1.70	STANDARD DEVIATION HOURS	.63	STANDARD DEVIATION HOURS	1.13

FIGURE 8 Engine (Object Codes 0800–0897).

engine adjustment activities. Adjusting engine timing and other minor repairs within a 1.25-hr period is acceptable.

- The average heavy repair time of 0.65 hr reflects the policy of conducting the most significant engine repairs at central maintenance. The dominance of half-hour repairs in this category reflects running bad order (RBO) repair activities. A 40-min standard for RBO repairs should be adopted for planning purposes.
- Remove-and-replace activities are the most frequently conducted activity, as expected, because of small-component change-out schedules and the policy of sending coaches to central maintenance for major repairs. The outlying observations in the 6- to 8-hr range reflect blower and turbocharger change-outs.

The investigation provides some good preliminary engine repair work standards. Inspections should be planned to take 30 min. An engine tune-up (light repairs) combined with an inspection should be planned to take 1.0 hr. Heavy repairs (e.g., RBOs), when combined with inspection, should be planned for 1.0 hr. Likewise, most remove-and-replace activities should be planned for 1 hr. These proposed preliminary standards provide sufficient time to inspect, repair, and test engines at the divisions. The proposed division-conducted engine repair standards do not incorporate use of dynamometers.

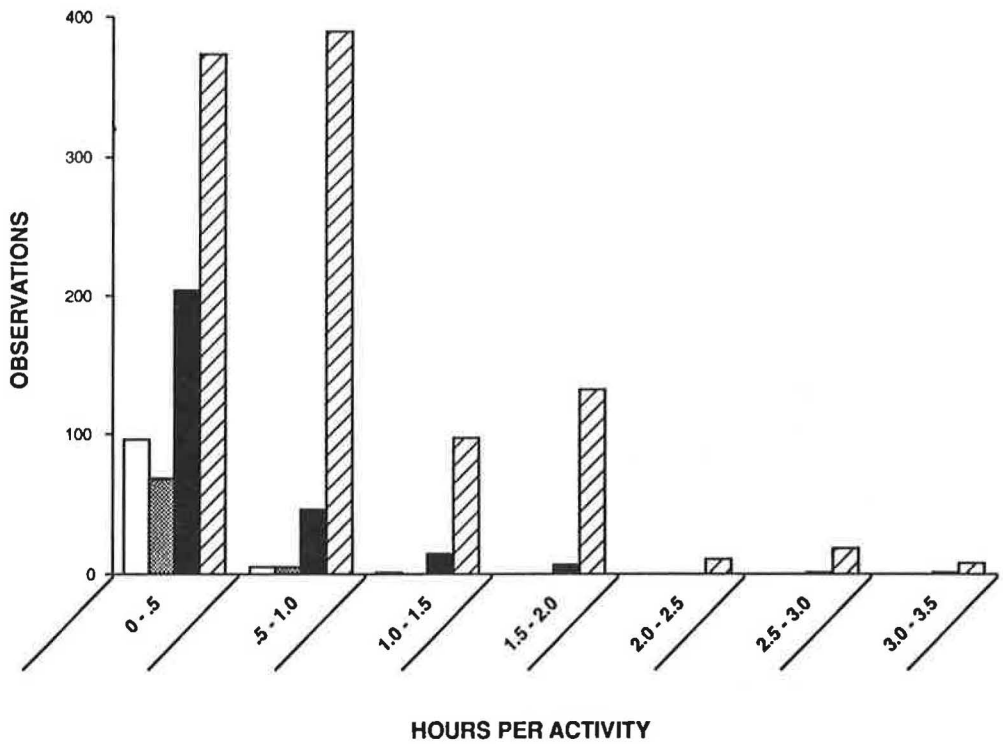
The relatively wide range of observed times for all engine maintenance activities highlights the need to tighten repair supervision. The light repairs requiring 3.5 to 4.0 hr should be rationalized. A review of division versus central maintenance repairs could improve control. Likewise, increased training in the diagnostics of engine repairs could tighten the distribution of repair times.

Air Group

Air group maintenance, like engine repairs, encompasses diverse major components including air starters, brake valves, and compressors. Many of these components have established change-out schedules that will influence the distribution of labor hour observation, as shown in Figure 9. The results of the research reveal the following:

- Inspections are typically completed within 20 min, indicating that troubleshooting an air system repair is not very difficult.
- Light repairs (e.g., adjustments) are also typically completed within 20 min.
- Heavy repairs, primarily associated with RBOs and unscheduled repairs, have only a slightly wider distribution and typically require 40 min to complete.
- Remove-and-replace activities have the widest distribution and the highest average repair time (1 hr), as expected. The complexity of removing some engine-mounted components, such as air starters and compressors, inherently broadens the distribution of repair times and increases the average.

For planning and scheduling air group repairs, the analysis indicates that a preliminary standard of 1 hr should be adopted



INSPECTION		LIGHT REPAIR		HEAVY REPAIR		REMOVE-N-REPLACE	
AVERAGE HOURS	.36	AVERAGE HOURS	.32	AVERAGE HOURS	.60	AVERAGE HOURS	1.06
STANDARD DEVIATION HOURS	.23	STANDARD DEVIATION HOURS	.21	STANDARD DEVIATION HOURS	.49	STANDARD DEVIATION HOURS	3.01

FIGURE 9 Air group (Object Codes 3000–3091).

for light and heavy repairs. This standard allows for both inspection and repairs. A remove-and-replace standard of 1 hr should also be adopted. Some remove-and-replace activities were observed to require 1 to 2 hr; an additional investigation should be conducted to determine the specific components serviced in this time interval.

Suspension Repairs

The labor-hour distribution of suspension repairs by activity is influenced by the frequent occurrence of flipped leveling valves, a condition frequently caused by errant operator behavior. Flipped leveling valves account for the dominance of light and heavy repairs under a half-hour long, as shown in Figure 10.

Experience at other transit agencies indicates that suspension repair times of 1 hr are typical. Many of the suspension repairs listed in the data base involved shock absorbers. The relatively frequent shock absorber repair rate, combined with radius rod replacement, should produce an average repair time greater than the observed average of almost 1 hr. The leveling valve problem is probably the cause for the lower remove-and-replace time. The changing of a leveling valve screen explains the high frequency of remove-and-replace observations under 1 hr.

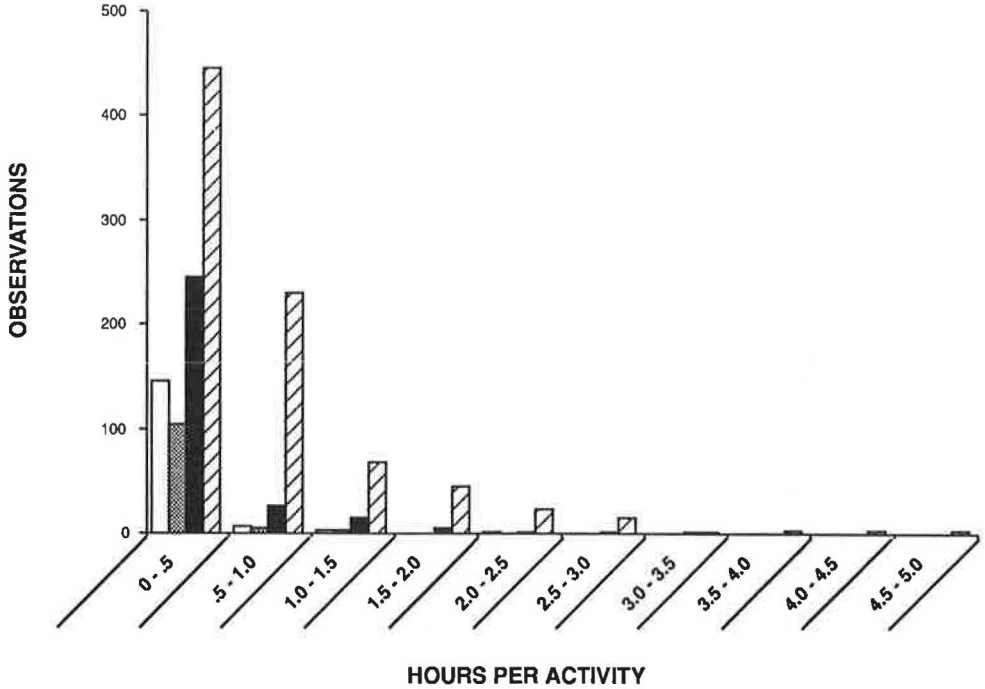
Removal of the leveling-valve-related remove-and-replace observations from the analysis increases the average remove-and-replace time to slightly under 1.25 hr. This average time is an acceptable standard for many suspension components. However, additional research is needed to establish standards for shock absorber and radius rod replacements.

Transmission

The policy of assigning all major transmission repairs except the removal and replacement of VH transmissions to central maintenance influences the distribution of repair hours, as shown in Figure 11. Almost all of the repairs occur in less than 1.5 hr. The repairs with greater duration are associated with VH transmission removal and replacement, particularly the repairs taking 5.5 to 6.0 hr and 7.5 to 8.0 hr.

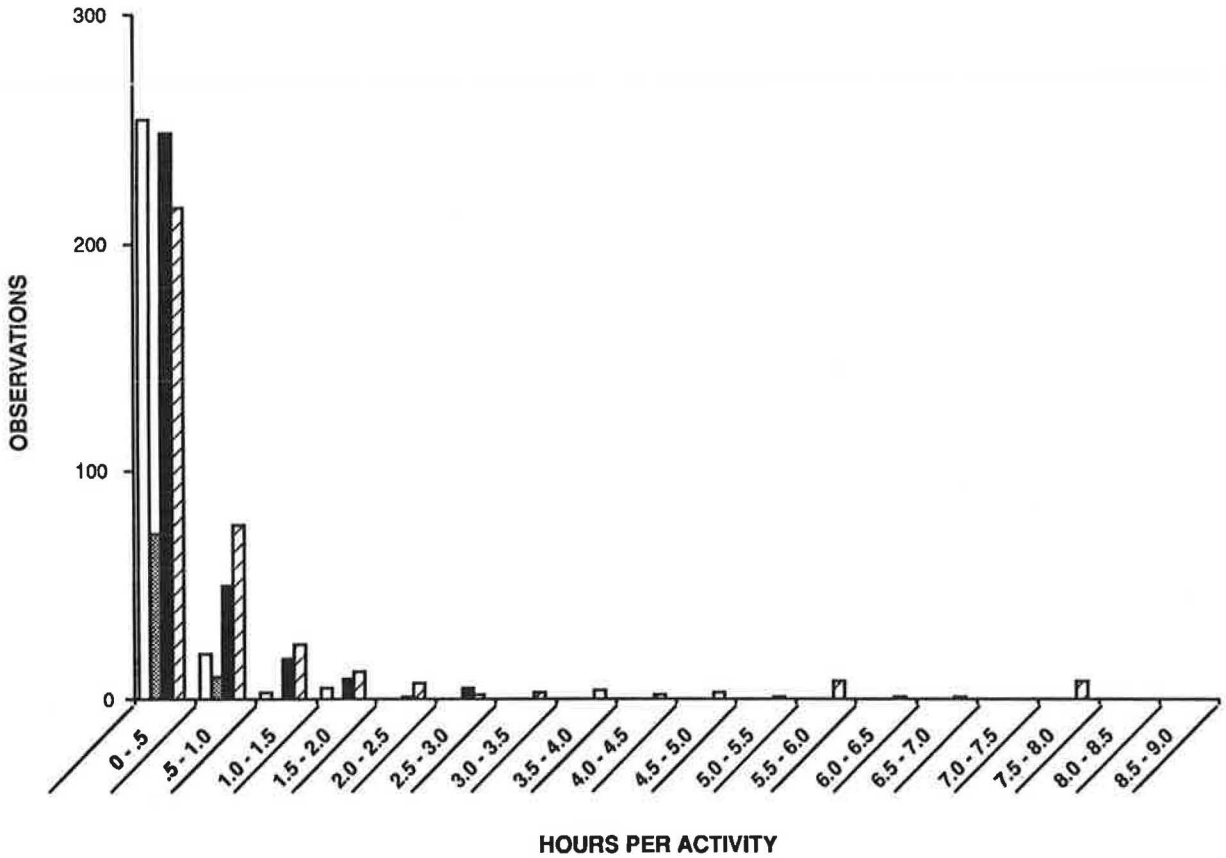
Remove-and-replace activities of 0.5 hr or less are associated with transmission pans, gaskets and o-rings, and pick-up screens. The dominance of heavy repairs of this same duration is also associated with these types of transmission repairs, plus transmission fluid leaks.

Inspections primarily involve the determination of where repairs should be performed (at division or central maintenance). In fact, the difference in time distributions of the four repair activities is small, indicating that mechanics are probably using different activity codes for similar repairs. Increased supervision of repairs and proper recording of activity codes on the work order should increase the relative differences in repair time distributions.



INSPECTION		LIGHT REPAIR		HEAVY REPAIR		REMOVE-N-REPLACE	
AVERAGE HOURS	.34	AVERAGE HOURS	.35	AVERAGE HOURS	.54	AVERAGE HOURS	.89
STANDARD DEVIATION HOURS	.29	STANDARD DEVIATION HOURS	.22	STANDARD DEVIATION HOURS	.54	STANDARD DEVIATION HOURS	.81

FIGURE 10 Suspension (Object Codes 1400–1492).



INSPECTION		LIGHT REPAIR		HEAVY REPAIR		REMOVE-N-REPLACE	
AVERAGE HOURS	.38	AVERAGE HOURS	.35	AVERAGE HOURS	.60	AVERAGE HOURS	1.11
STANDARD DEVIATION HOURS	.29	STANDARD DEVIATION HOURS	.20	STANDARD DEVIATION HOURS	.51	STANDARD DEVIATION HOURS	1.58

FIGURE 11 Transmission (Object Codes 1700–1792).

On the basis of these observed repairs, a preliminary work standard for division-performed transmission repairs should be 0.5 hr for inspections. The time standard for light repairs should be 0.75 hr and for heavy repairs, 1.0 hr. These standards incorporate both the inspections and the diagnostic phase of repair. For VH transmissions, a remove-and-replace standard of 6.0 hr should be used. A 6-hr standard indicates that the work can be completed in one shift by trained mechanics while still allowing for unproductive times such as report, clean-up, breaks, and lunch periods. Increased attention to the correct recording of activity codes on repair orders should decrease the number of remove-and-replace observations by a little less than 5 hr.

Cooling System

The final major component group is the cooling system. This group accounted for 3.5 percent of the divisions' repair labor hours. The individual components within the group cover both water- and oil-cooling equipment.

The results of the research, shown in Figure 12, indicate that most repairs are performed in less than 1 hr. The dominant repair is component remove-and-replace activity. The frequency of remove-and-replace activities lasting less than 0.5 hr reflects the changing of filters. Removing the filter-change observations from the data base increases the average remove-and-replace time to 1.4 hr. This duration is representative for the change-out of coolers, pumps, radiators, and heater cores. The replacement of pipes and hoses is expected to take less time. Therefore, a preliminary remove-and-replace standard for cooling system components, excluding filters, should be 1.5 hr. Obviously, some repairs will take longer, but the 1.5-hr standard provides managers with a planning benchmark.

Heavy repair activity is the second most frequent repair. Few heavy repair times were greater than 1.5 hr. For planning purposes, a preliminary standard of 1.0 hr, which includes inspection and repair times, should be used.

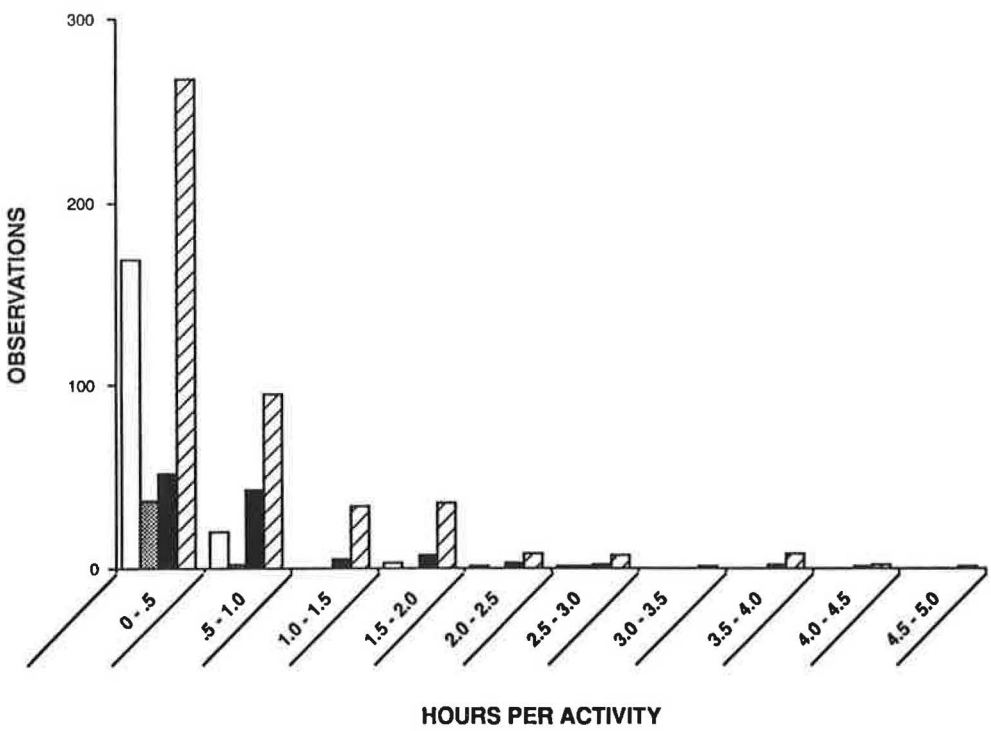
Too few light repair observations were contained in the data base to draw any conclusions.

IMPLICATIONS FOR MAINTENANCE MANAGERS

To plan and control maintenance cost, managers must understand how resources are applied and must apply tools to increase the use of applied resources. This methodology illustrated the use of MMISs to identify preliminary work standards for planning and controlling workforce labor.

The methodology also identified opportunities for improved performance through the evaluation of specific repair activities. The use of engineering resources to address repair time groups that vary significantly from observed repair time averages provides maintenance managers with additional opportunities to control resources.

The research identified 10 component groups that account for more than 85 percent of maintenance labor. To improve



INSPECTION	LIGHT REPAIR	HEAVY REPAIR	REMOVE-N-REPLACE
AVERAGE HOURS .43	AVERAGE HOURS .38	AVERAGE HOURS .68	AVERAGE HOURS .95
STANDARD DEVIATION HOURS .39	STANDARD DEVIATION HOURS .45	STANDARD DEVIATION HOURS .73	STANDARD DEVIATION HOURS 1.02

FIGURE 12 Cooling system (Object Codes 0600–0692).

maintenance performance by providing managers a guideline for planning and controlling maintenance activities, 23 standards were identified. By applying these preliminary work standards, workforce use can be improved and the need for additional mechanics avoided. Increasing productivity levels by 10 percent, a feasible objective through use of standards, would prevent the need to hire additional mechanics (*4*). The application of a maintenance manpower planning model indicated that a 10-mechanic shortage was present at the host agency (*6*). This labor shortage could be overcome by the use of preliminary standards.

The preliminary work standards presented here can be applied to transit operations across the country. More valuable to maintenance managers is the illustration of the methodology used to develop the initial standards. This methodology can be applied by managers responsible for all aspects of maintenance, regardless of industry affiliation.

REFERENCES

1. T. H. Maze. *Bus Fleet Management Principles and Techniques*. Report DOT-T-89-20. UMTA, U.S. Department of Transportation, 1987.
2. K. Inaba. *NCTRP Synthesis of Transit Practice 4: Allocation of Time for Transit Bus Maintenance Functions*. TRB, National Research Council, Washington, D.C., 1984.
3. *Evaluation of Life Cycle Costs for the Procurement of Transit Buses*. UMTA, U.S. Department of Transportation, 1982.
4. G. C. Haemisch and F. G. Miller. Increasing Productivity in Bus Maintenance Functions. *Proc., AIIE Spring Conference*, 1976.
5. U. Dutta et al. Effectiveness of Improved Repair Scheduling on Performance of Bus Transit Maintenance. In *Transportation Research Record 1066*. TRB, National Research Council, Washington, D.C., 1986.
6. *NCTRP Report 33-3: Public Transit Bus Maintenance Manpower Planning*. TRB, National Research Council, Washington, D.C., 1984.
7. L. R. Davis. Productivity Improvements in Equipment Maintenance: TRANSMIS at SCRTD. In *Managing Transportation as a Business*, American Society of Civil Engineers, 1987, pp. 277–286.
8. J. N. Baijpai. Economic Evaluation of Bus Maintenance Contracting. In *Transportation Research Record 1164*, TRB, National Research Council, Washington, D.C., 1988.

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