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RESEARCH FINDINGS TO AID
SUPERVISORS AND TRAINERS IN
IMPROVING MAINTENANCE PERFORMANCE

Training and Simulation Technical Area
Training Research Laboratory

November 1983



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→ The group of activities requiring use of special tools or technical specifications is comprised predominantly of adjust activities, but also contains some remove, install/replace, and service activities. The performance of 71% of the mechanics in these activities resulted in one or more serious uncorrected errors remaining in the equipment upon completion of the maintenance task. The majority of these errors reflected either a failure to use specifications or failure to use them correctly. By contrast, only 22% of the mechanics performing activities not requiring special tools or specifications left serious uncorrected errors in their work. For tasks allowing final checkout to verify successful completion of the maintenance task, 66% of the mechanics either failed to perform the checkout or did so incorrectly.

These findings provide a basis for immediate actions which can be taken at the unit level to improve the quality of maintenance. Maintenance activities exhibiting a high probability of mechanic errors are identified for unit supervisor and trainer use in setting priorities for work assignments requiring closer supervision and checking. On-the-spot correction and guidance given to the mechanic performing these work assignments can provide the feedback necessary to develop maintenance proficiency through job experience. ↗

The purpose of this report is to provide information to assist supervisors and trainers in identifying those activities that mechanics are least likely to perform correctly and the types of errors they are most likely to make.

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RESEARCH FINDINGS TO AID SUPERVISORS AND TRAINERS IN IMPROVING MAINTENANCE PERFORMANCE

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FOREWORD

The work reported herein is part of ARI's research program in maintenance performance and use of maintenance information. It represents baseline data that were collected to establish the nature of organizational maintenance practices to guide subsequent research efforts aimed at improving maintenance performance. It was decided that the information about mechanic performance could be of direct utility to maintenance supervisors by identifying high frequency errors that can be reduced by timely supervision and correction. The purpose of this report is to provide maintenance trainers and supervisors that information.



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RESEARCH FINDINGS TO AID SUPERVISORS AND TRAINERS IN IMPROVING MAINTENANCE PERFORMANCE

EXECUTIVE SUMMARY

Requirement:

Provide a diagnostic description of mechanic performance of organizational level maintenance tasks, highlighting major performance problems. Identify maintenance activities that, if targeted for corrective action, will enable trainers and supervisors to achieve the greatest gains in mechanic proficiency and equipment readiness.

Procedure:

The present analysis is based on data collected as part of a broader research program undertaken to develop methods for improving predictions of job-site information needs. In accomplishing this research, detailed on-site observations were conducted on 236 organizational level mechanics located in five U.S. Army combat arms divisions. Mechanics were individually observed while performing regularly assigned, organizational level maintenance tasks in their normal shop environments. Detailed, step-by-step observations were recorded. Activities occurring during performance of a task were analyzed into "remove," "install/replace," "adjust," and "service" activities. Performance of these activities by mechanics possessing three levels of task experience was analyzed for use of information sources, types of information sought, occurrence of errors, types of errors made during performance, and types of serious, uncorrected errors remaining upon completion of performance.

Findings:

Data from this research indicate that there are significant deficiencies that occur regularly in organizational level mechanic performance. These errors, however, are located mainly within types of maintenance activities that can be tagged for closer supervision prior to assignment.

The majority of substandard performances and failures to perform critical actions occur primarily in two types of task activities:

- activities requiring use of special tools and/or technical specifications, and
- final operational checkouts to verify the success of maintenance actions.

The group of activities requiring use of special tools or technical specifications contains most adjust activities and some kinds of install/replace activities. The performance of 71% of the mechanics in these activities resulted in one or more serious uncorrected errors remaining in the equipment upon completion of the maintenance task. The majority of these errors reflected either a failure to use specifications or failure to use them correctly. By contrast, only 22% of the mechanics performing activities not requiring special tools or specifications left serious uncorrected errors in their work. For tasks allowing final checkout to verify successful completion of the maintenance task, 66% of the mechanics either failed to perform the checkout or did so incorrectly.

Conditions contributing to the occurrence and repetition of errors include the following:

- The mechanic performing the task is the sole judge of when the task is finished and is accomplished to maintenance standards.
- Coworkers are used as the major source of task information.
- The way the task has been performed in the past is the standard for how it should be performed.
- Maintenance practices which degrade equipment readiness are not recognized and continue to be employed.
- Mechanics are unaware of the need to perform certain activities to specific standards.

Under these conditions it is unlikely that mechanic performance can improve with experience. This was borne out by the results of the analysis of error patterns for mechanics with varying levels of task experience. This analysis indicated that there was virtually no difference in the frequency or types of errors committed between experienced and inexperienced mechanics. This lack of improvement is attributed primarily to the absence of corrective feedback to the individual mechanic, either from his supervisor or from performing final operational checks.

Utilization:

These findings have important operational and research implications. They provide a basis for immediate actions which can be taken at the unit level to improve the quality of maintenance. Maintenance activities exhibiting a high probability of mechanic errors are identified for unit supervisor and trainer use in setting priorities for work assignments requiring closer supervision and checking. On-the-spot correction and guidance given to the mechanic performing these work assignments can provide the feedback necessary to develop maintenance proficiency through job experience.

Research efforts directed at the improvement of maintenance must take these findings into account if new procedures, techniques, or aids are to

be effective. Unless there is a shop management system that enforces standards and corrects errors, such advances as improvements in the quality of technical information, job aids, or training will not have their full desired impact on performance. Results of this research are being used by the Army Research Institute in subsequent research to develop maintenance performance information and training systems for maintenance managers and supervisors.

RESEARCH FINDINGS TO AID SUPERVISORS AND TRAINERS
IN IMPROVING MAINTENANCE PERFORMANCE

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RESEARCH FINDINGS TO AID SUPERVISORS AND TRAINERS
IN IMPROVING MAINTENANCE PERFORMANCE

OBJECTIVE OF THIS REPORT

A maintenance supervisor's first priority is to accomplish the shop's mission of keeping the unit's vehicles in operational condition. This mission remains in first priority regardless of the level of experience and proficiency his small work force may possess for the various maintenance tasks that need to be performed. Thus, in making work assignments, the question frequently is not who has demonstrated competence in performing particular tasks, but who is available to do the work. Under these conditions, the supervisor needs some way of identifying when checking and corrective feedback is going to be essential and when he can expect work to be completed to acceptable standards without close checking and corrective guidance. This same kind of information can assist trainers in identifying the kinds of maintenance skills they can expect trainees to acquire readily versus those that will be acquired only through intensive training.

The purpose of this report is to provide information to assist supervisors and trainers in identifying those activities that mechanics are least likely to perform correctly and the types of errors they are most likely to make. This information is expected to be useful in focusing corrective attention on specific areas of performance that promise the greatest returns in improving mechanic proficiency and the readiness condition of a unit's vehicles.

METHOD

Observing Performance at the Work Site

The research on which this report is based is unique because it represents the first systematic effort to identify how mechanics go about performing maintenance tasks under conditions as they exist in the actual

job setting.¹ To conduct this research, a method was developed for observing and recording mechanics performing tasks assigned to them under the usual assignment practices employed in their shop. The observer did not intervene during task performance. No special arrangements were made to insure that the proper tools, manuals, or other resources were readily available to the mechanic while performing the assigned work. In other words, with the exception of the observer's presence, conditions were just as they would have been if the observer had not been present.

Before conducting the observations, detailed task analyses were developed on a large pool of tasks which organizational level mechanics are expected to perform on five types of vehicles. The five types of vehicles were the M60 tank series, M113 personnel carrier series, M151 1/4-ton truck series, the M35 2 1/2-ton truck series, and the M54 5-ton truck series. During the task performance the observer recorded a written description, in a step-by-step fashion, of:

- a. activity being performed and how it was performed
- b. when information was sought in the context of the ongoing activity
- c. source and identity of information sought and obtained
- d. errors made--corrected, uncorrected, and omissions

An example of the detailed recording of a mechanic's performance is provided in the Appendix. Following observation, each mechanic was interviewed to obtain information on how often he had performed the task observed and length of time on the job. Any questions the observer had regarding a mechanic's performance were resolved at this time.

¹This research was conducted by Dr. Donald L. Schurman, Project Director, Applied Science Associates, Inc., under contract with the US Army Research Institute. Unless otherwise noted, the analysis of data presented in this report was performed by Dr. Richard P. Kern, US Army Research Institute, on data provided by the Contractor. The methodology developed and used in collection of this data is presented in: Schurman, D. L., Porsche, A. J., Garbin, C. P., & Joyce, R. P. Guidelines: Assessing use of information sources and quality of performance at the work site (Research Note 82-7). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences (ADA125366).

Only tasks that directly involved mechanical maintenance were observed. Assignments that involved only inspection of equipment, such as quarterly inspections, were not observed for this purpose. With this exception, the tasks observed were sampled from the daily workload being performed in each shop. As a result, these observations are based on the commonly occurring, "bread and butter" tasks performed at the organizational maintenance level.

Identifying the Specific Maintenance Activities Performed

Tasks, as identified by the training and job analyst, occur in varying numbers and across a wide variety of work assignments performed by the mechanic in the unit. For example, "adjust wheel bearings" may reflect the only major activity in this assignment and involve only gaining access to the bearing adjusting nut, making the adjustment, and then replacing the lifting eye. On the other hand, the activity "adjust wheel bearings" is also embedded in the more involved work assignment of "remove and install wheel bearings and seals."

Work performed by other mechanics prior to the work assignment under observation also influences the maintenance activities required by the assignment. For example, installation of a part may, in one assignment, be embedded in a complete remove and install sequence of activities. In another assignment of the same install task, the removal activities have already been accomplished by someone else, and the present assignment involves only the install activities. As a result, diagnostic information relating mechanic information needs and performance errors to the specific kind of work being performed cannot be provided on the basis of the more general label used in identifying the work assignment.

To provide a better basis for developing diagnostic information, specific maintenance activities were identified that were embedded in each mechanic's performance of his work assignment. The specific maintenance activities identified were "remove," "install/replace," and "adjust" activities. "Troubleshoot" and "service" activities were also identified but did not occur with enough frequency to provide a basis for the full analysis.

In addition to examining performance on each type of activity, these activities were sorted into two groups, those not requiring use of special tools and/or technical specifications and those requiring their use for performance to maintenance standards. The types of maintenance activities contained in each of the two groups and the number of mechanics observed in each case are shown in Table 1.

Table 1

**NUMBER OF MECHANICS OBSERVED
IN EACH TYPE OF MAINTENANCE ACTIVITY**

Type of Activity	Number of Mechanics
A. Requires use of special tools/ technical specifications	
Install/replace	32
Adjust	70
B. No special tools/technical specifications required	
Install/replace	61
Remove	73
Total	236

Identification of the presence or absence of the requirement for special tools and/or technical specifications was based on the task analyses completed by the research staff prior to conducting the observations. Special tools were defined as tools and test equipment called for in the Technical Manual (TM) which are not found in the mechanic's personal tool box.² Torque wrenches, test equipment, pullers, and bearing packers are examples of those that were considered special tools. Technical specifications were defined as settings or judgment standards specified in the TM for performance of that specific activity.

²Data for this research were collected during the 1978-1980 time period. The older style Technical Manuals had not yet been replaced by Skill Performance Aids (SPA) or "new look" manuals.

Assessing Quality of Mechanic Performance

Quality of performance was evaluated from three perspectives: skill and efficiency in carrying out the performance, the serviceability status of the equipment upon completion of the performance, and the mechanic's use of final checkout procedures to verify the operational condition of the equipment.

Process errors: skill and efficiency exhibited during performance.

The objective in recording process errors was to identify all of the errors made during performance, whether or not they were serious errors and whether or not they were corrected before completion of the work assignment. Process errors reflect the mechanic's ability to organize and apply his knowledge of the anatomy and functioning of the equipment, what needs to be done, how to do it, and the tools or other equipment needed to accomplish the maintenance activity. Since operational vehicles and shop resources frequently conspire to provide unique surprises, we would not expect even highly proficient mechanics always to perform without making any process errors. However, we would expect mechanics who have performed the task many times to be less likely to make process errors than mechanics who have never performed the task before.

Serious uncorrected errors: serviceability status upon completion of work. Serious uncorrected errors are process errors that were not corrected and that resulted in one or more of the following conditions: immediate damage to the equipment, safety hazards in operating the equipment, and shortened serviceable life of the equipment. Presence of serious uncorrected errors means that the mechanic has considered the work assignment accomplished and has either not recognized the presence of the error or has not considered it sufficiently important to take corrective action.

Final check errors: knowledge and use of operational checkout procedures.

Checkout errors were scored only when it was possible for the mechanic under observation to have performed the checkout. For example, final checkouts are not possible in some cases because replacement parts are not available or the vehicle is disabled for some other, unrelated reason. Errors were scored in terms of failure to perform the checkout and failure to perform it correctly.

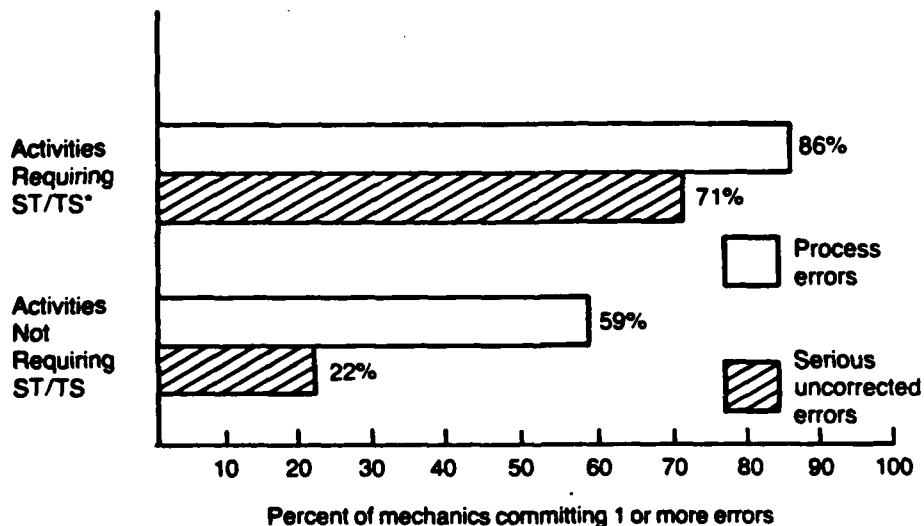
OVERVIEW OF MAJOR FINDINGS

Major Areas of Performance Problems

Mechanic performance is most likely to fail to meet maintenance standards when achievement of these standards requires performance of either of two types of task activities.

Activities Requiring Special Tools and/or Technical Specifications

Figure 1 provides a summary of mechanic performance under these conditions. This figure shows that 86% of the mechanics performing activities possessing these special requirements made one or more process errors during the performance. Of greater concern is the 71% whose work still reflected one or more serious uncorrected errors when the mechanics considered the assignment completed. As a general estimate, this means that only about 30 out of every 100 vehicles brought in for this type of maintenance action leave the shop in good operational condition. By contrast, if the maintenance performed does not require the mechanic to use special tools and/or technical specifications, the probability of the vehicle leaving the shop in good condition is much higher, about 78 out of 100 times.



* ST/TS: Special tools/technical specifications.

Figure 1. Error performance by type of activity performed.

Activities Requiring Checkout to Verify Successful Completion

Figure 2 provides a breakout of mechanic performance on checkout tasks by experience level. Overall, 66% of the mechanics performing tasks permitting checkouts either failed to perform the checkout or performed it incorrectly. Experienced mechanics were more likely to perform checkouts than were the inexperienced mechanics. However, experienced mechanics were no more likely to perform the checkout correctly than were the inexperienced mechanics who did perform them. Failure to accomplish these checkouts allows process errors to remain as serious uncorrected errors after the mechanic considers the work completed.

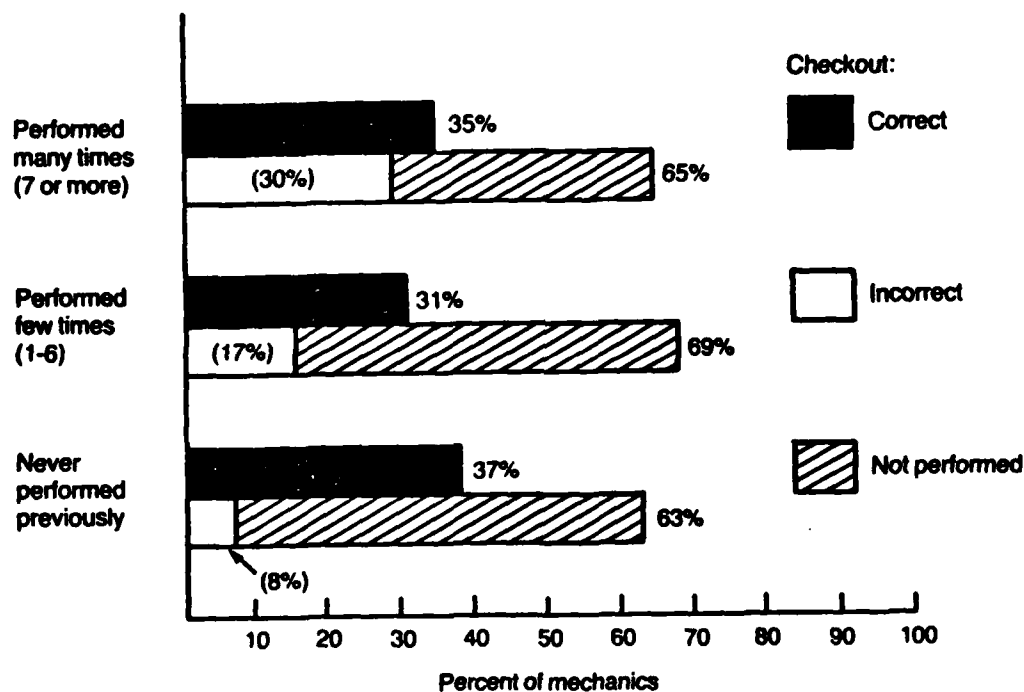


Figure 2. Checkout performance by mechanics at different levels of prior task experience. (Analysis provided by D. L. Schurman, A. J. Porsche, and R. P. Joyce, Applied Science Associates, Inc.)

A Diagnostic Description of Mechanic Performance

Information Sources Guiding Mechanic Performance

Mechanics' main source of information is the equipment. Mechanics direct and guide their activities by studying and observing what happens as they attempt to carry out an action or step. Of the 236 mechanics, only 36% sought task-related information from other personnel or Technical Manuals (TM). Other personnel and TM are used as information sources after their study and observation of the equipment leaves them uncertain as to what to do or how to resolve a problem. The presence of this uncertainty is reflected in Figure 3 which shows the greater probability of a process error occurring during the performance of those who seek information as opposed to those who do not seek information assistance. When information is sought, it is generally to deal with circumscribed problems, not with full, step-by-step procedures.

Coworkers are more frequently used than TM as a source of information. Coworkers are the preferred source of information at all experience levels. Figure 4 shows that only about one-half of the inexperienced mechanics who seek information use TM as a source and even this use is generally in addition to consulting coworkers. Experienced mechanics who seek information virtually never use TM but, instead, rely on other personnel for their information assistance.

Effects of Increased Experience on Proficiency

Increased experience "stamps in" past performance as the standard. As shown in Figure 4, the probability of mechanics seeking information from another person or from a TM decreases sharply as mechanics gain experience in performing the task. About 60% of those observed performing a task for the first time sought information from another mechanic and/or a TM. In contrast, only 18% of the mechanics who had previously performed the task "many times" sought information from one or both of these sources. As a result, the way tasks have been performed in the past provides the most important source of guidance, whether or not the mechanic seeks information assistance. This guidance is what is stored in the mechanic's head and may or may not conform to what is in the TM.

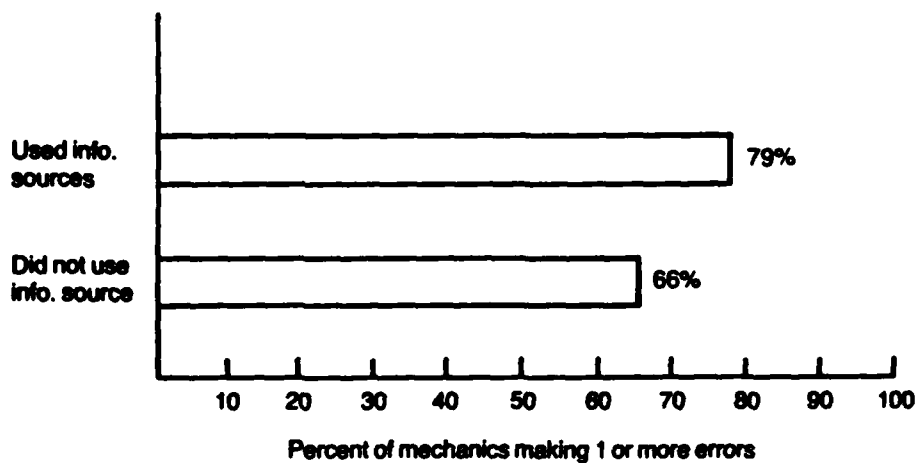


Figure 3. Occurrence of process errors in relation to whether or not mechanics used information sources.

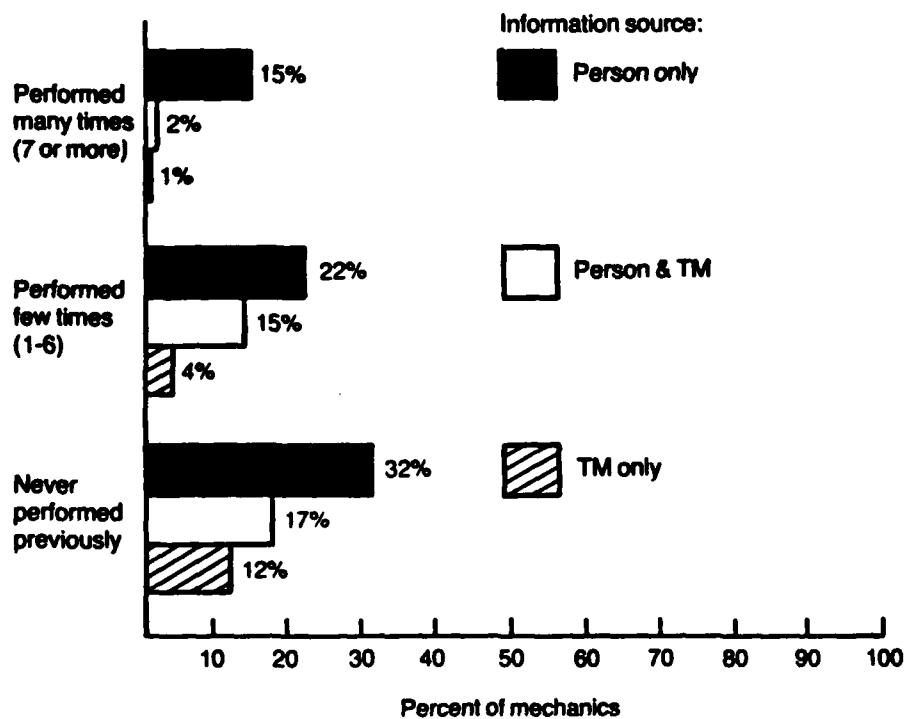


Figure 4. Information sources used by mechanics at different levels of experience.

Quality of performance may not improve with increased experience.

Figure 5 shows that experienced mechanics who have performed the work assignment many times are just as likely to make errors as new mechanics who have never performed the tasks before. Experienced mechanics do not differ from inexperienced mechanics in the level of skill and efficiency exhibited during the performance (process errors) and are about as likely as inexperienced mechanics to leave serious errors uncorrected when the work is considered completed. In addition, Figures 6 and 7 reveal that there is no difference in the types of errors made by experienced and inexperienced mechanics. These findings hold whether or not the maintenance assignment requires use of special tools and/or technical specifications.

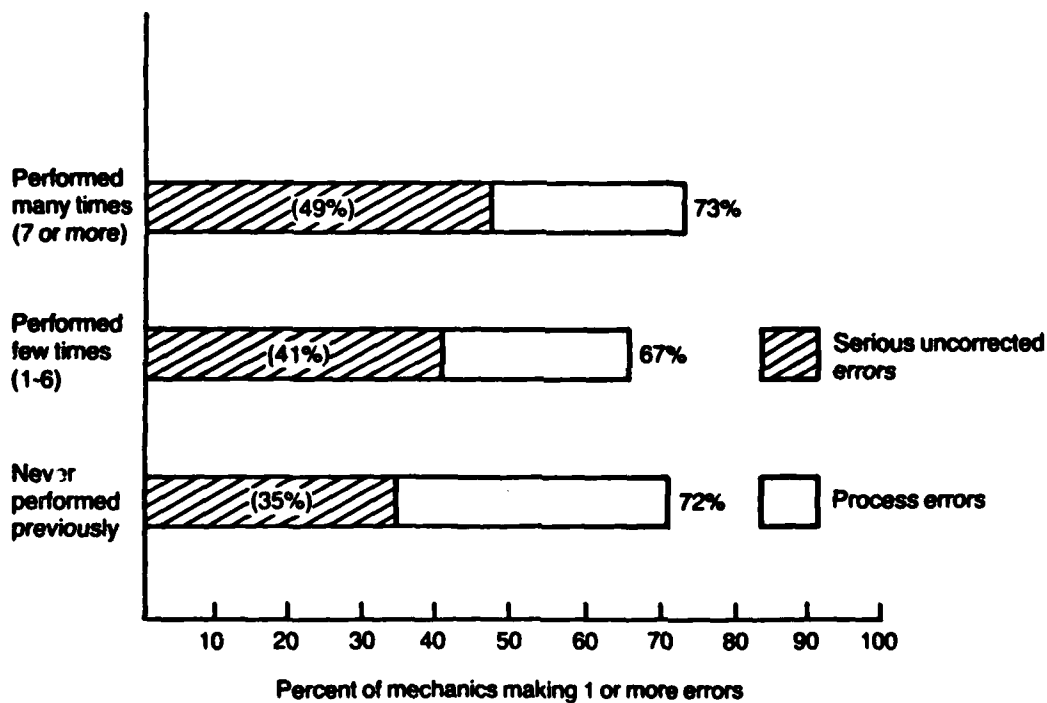


Figure 5. Error performance by mechanics at different experience levels.

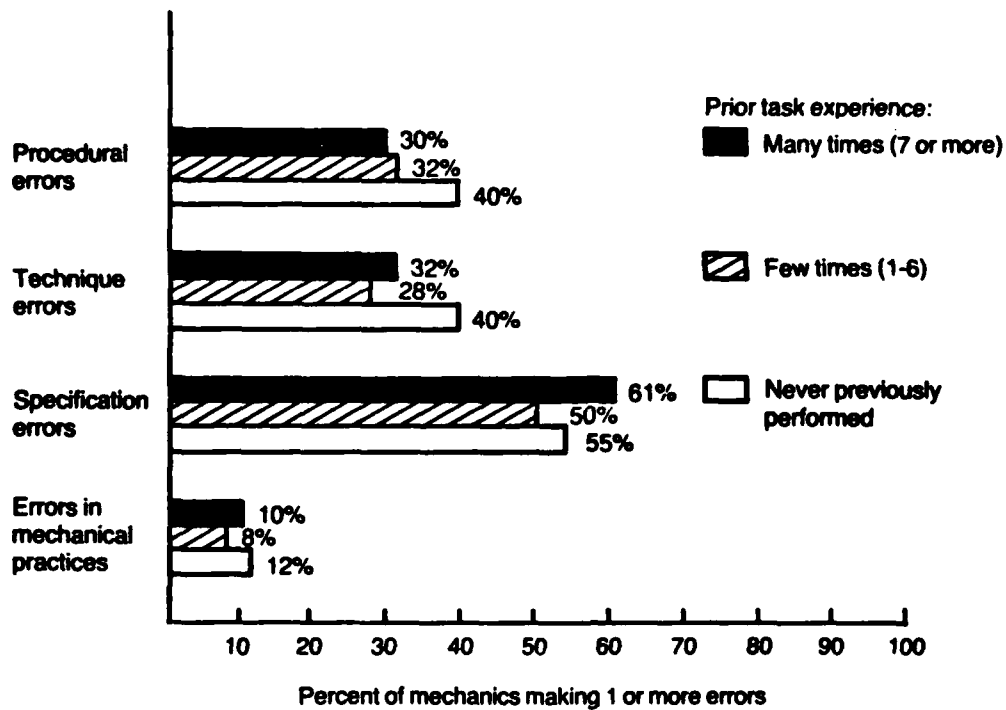


Figure 6. Types of process errors made by mechanics at different experience levels.

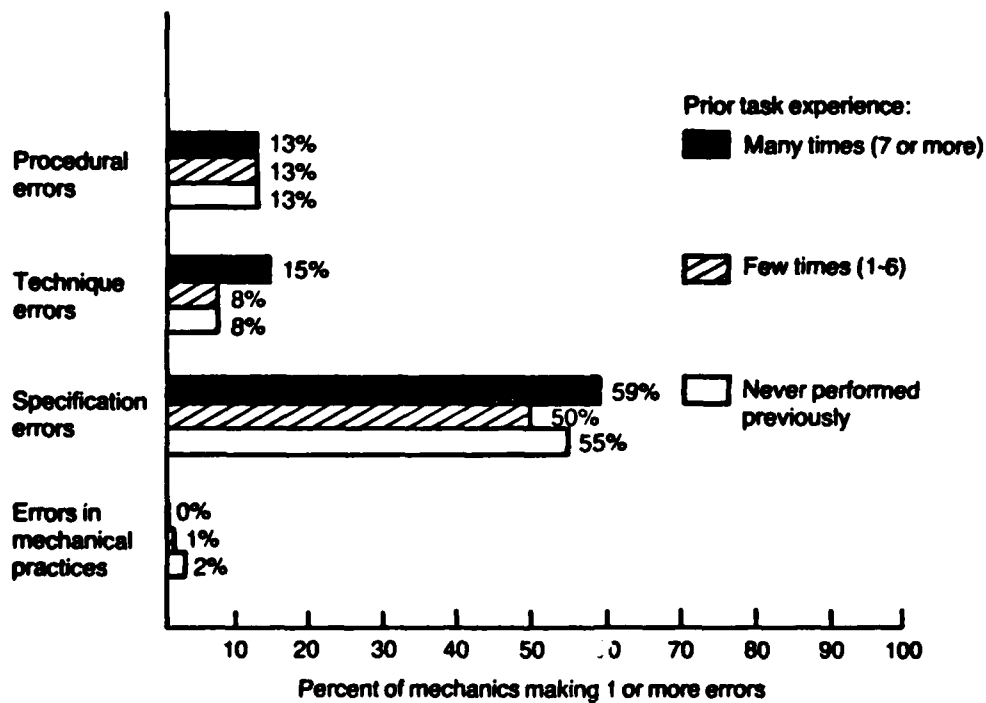


Figure 7. Types of serious uncorrected errors made by mechanics at different experience levels.

Major Conditions Retarding Development of Proficiency

The mechanic is the sole judge of the adequacy of his own work.

Observations revealed that in most shops the mechanic performing the work was left to interpret the adequacy of his own performance. In general, the ability to make this interpretation skillfully depends on the same type of knowledge needed to perform the task to standards in the first place. Thus, mechanics initially lacking this expertise are caught in a vicious circle of trying to judge adequacy of performance without the knowledge needed to recognize criteria important to this judgment. Without the necessary checking and correcting of performance to standards provided by a mechanic who knows the standards, they frequently do not learn to identify critical errors in performance. As they become the "experienced" mechanics in the shop, the way they have performed the task in the past becomes the standard they pass on to the inexperienced mechanics. Recordings of the on-site observations illustrate that remove, install, adjust, and service activities can eventually be accomplished in some fashion or other through persistent trial and error efforts. However, "accomplished" does not necessarily mean "accomplished to standards."

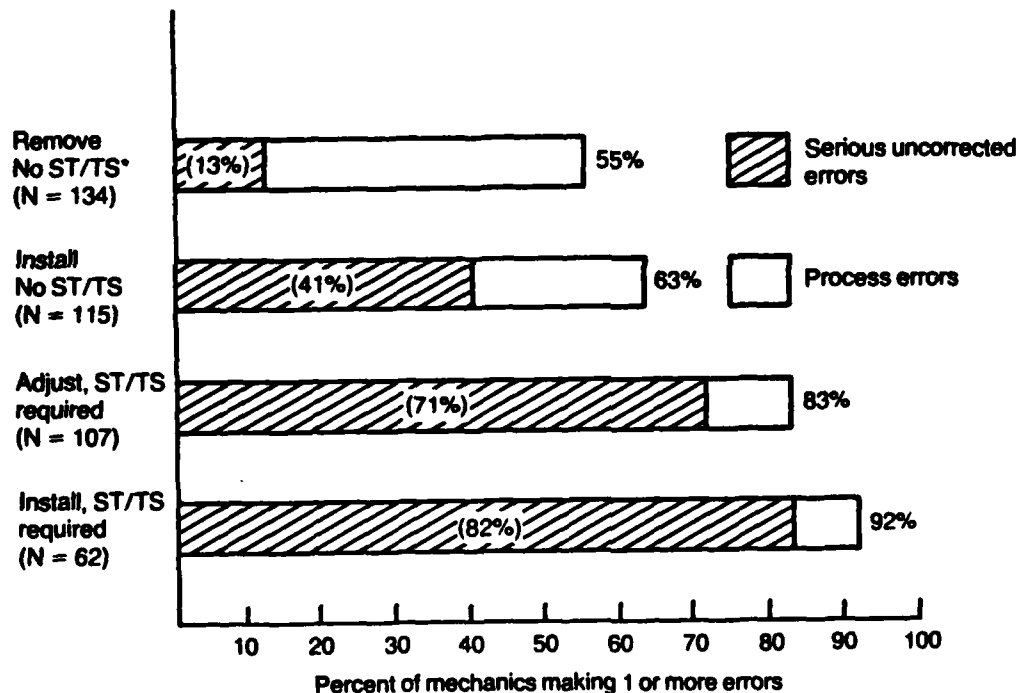
Development of proficiency requires corrective feedback. Observations suggest that equipment readiness problems occur when future performance of the vehicle depends on how these procedures were carried out. For example, a mechanic can install wheel bearings and seals using a hammer and screwdriver and assume that the job is properly accomplished once the parts are in place. However, the damage frequently done to the bearing and seals using such procedures will, in the near future, put the vehicle out of operation. Without the benefits of learning from corrective feedback, a mechanic's judgment of when a task is successfully completed is not likely to include consideration of the standards required (the how) for effective maintenance.

USING SPECIFIC FINDINGS TO IMPROVE MAINTENANCE

A Strategy for Identifying Problem Areas in Work Assignments

The Probability of Errors in Major Maintenance Activities

Figure 8 presents the number of mechanics who made errors and who left serious errors uncorrected in performing each of four types of major maintenance activities. These percentages can be used as estimates of the probability of mechanics making errors when performing each type of activity shown in the table. Using these estimates, the probability of mechanics making either process errors or serious uncorrected errors is lowest for remove activities and highest for install activities which involve use of special tools and/or technical specifications.



* ST/TS: Special tools/technical specifications

Figure 8. Error performance of mechanics on each of four types of maintenance activities.

Differences in the probabilities of mechanics making errors in performing different types of maintenance activities reflect the opportunities present for making errors as well as the level of mechanic proficiency. For example, most remove activities present fewer opportunities for a person to proceed without correcting order-of-step errors than do install activities. Damage to the equipment through trying to remove parts out of sequence or through improper use of tools is virtually the only type of serious error that can remain uncorrected when performing remove activities.

By contrast, install activities provide opportunities for procedural and technique errors in addition to those possible during remove activities. For example, common serious install errors include failure to use a required part, such as lock washers, or incorrect positioning of the part, such as reversing a check-valve in a hydraulic line. Opportunities for making technique errors which result in damage to the equipment are greater during install than during remove activities. For example, damage to bearings and seals caused by installing them with a hammer and screwdriver is not easy to detect once they are in place and cannot be closely examined.

Requirements for use of special tools and/or technical specifications in performing an activity introduce opportunities for errors in addition to those sketched above for common remove and install activities. These requirements exist in some form for almost all adjust activities. Error opportunities increase because now the mechanic is required to recognize when specs are called for and to know the techniques required for using special tools and for applying the specs.

Setting Priorities for Checking Mechanic Performance

The differences in the probability of errors for the activities shown in Figure 8 suggests the importance of recognizing these differences in setting priorities for specific areas of performance most in need of trainer and shop supervisor attention. If, for example, mechanics rarely make errors in performing remove activities, this suggests that, when face-to-face with the equipment, they already possess the skills and knowledges generally needed to perform these activities. With one exception then,

trainers, manual developers, and supervisors could feel comfortable in giving these activities very low priority for detailed attention. On the other hand, a high probability of mechanic error in performing adjust and specific types of install activities suggests the need for placing these high on the priority list for attention during training and performance on the job. The one exception would be in special cases where occurrence of an error has a high probability of causing an injury or serious damage to the equipment. For example, removing a power pack from a tank might be this type of special case.

Identifying Specific Types of Errors for Corrective Action

Information on the kinds of errors mechanics are most likely to make and the reasons mechanics make these errors can help trainers and supervisors plan effective corrective action. The percent of mechanics who made each of the four types of errors is shown in Figure 9. The following sections describe each of these types of errors and conditions contributing to the occurrence of these errors.

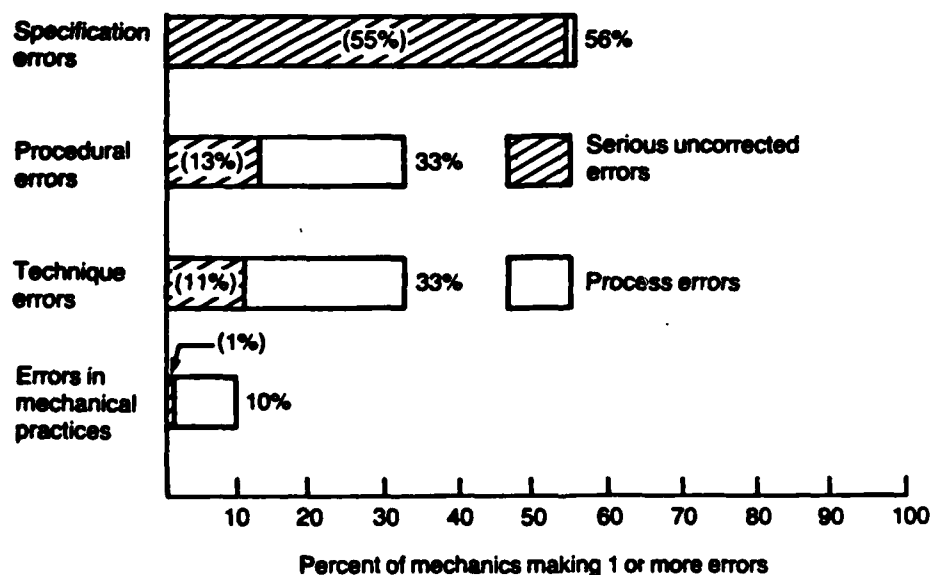


Figure 9. Error performance of mechanics by types of errors made.

Specification Errors

Description. Specification errors reflect failure to use special tools, improper use of special tools, or failure to apply the correct specification. Examples of observations involving specification errors of both types are found in activities requiring use of torque values in installing carburetors, spark plugs, manifolds, brake slave cylinders, track road wheels, and in adjusting wheel bearings and various lock nuts related to other adjust activities. Other types of specification errors include failure to use, or to use correctly, feeler gauges in adjusting spark plugs, engine valves, contact breaker points, and brake shoe clearance. Still other types of specification errors include failure to use, or to use properly, strain gauges in adjusting steering brake linkages (M113), timing lights in adjusting engine timing, tachometers in adjusting engine idling speed, and gauges used in adjusting wheel toe-in.

Probability of occurrence. Examination of Figure 9 shows that, of the four types of errors, mechanics are most likely to make specification errors, and these errors nearly always persist as serious uncorrected errors. Using Figure 9 as the basis, supervisors could expect mechanics to make one or more specification errors while performing 56 out of 100 assignments requiring use of specifications. Serviceability of the equipment could be expected to be impaired, either immediately or over a longer term, in about 55 out of every 100 assignments involving specifications.

Contributing causes. Specification errors remain uncorrected because of at least three, closely interrelated reasons presented below.

1. Lack of awareness of the need for specifications. The type of specification encountered most frequently at the organizational level is the requirement for installing or adjusting components to certain torque wrench settings. The equipment, however, is not designed to identify bolts or components that require tightening or adjusting to these standards.

Mechanics direct and guide their activities by studying and observing the equipment and what happens when they attempt to carry out an action or step. They go to other personnel or TMs for information only when their study and observation of the equipment leaves them uncertain as to what to do or how to resolve a problem. When they reach the point in a procedure where they are expected to torque a nut to a certain specification, there is nothing about the nut that suggests the need for a special tool or for tightening to special standards. Failure to recognize the need for specifications is reflected by the small number of mechanics, reported below, who sought information on specifications.

Lack of awareness of the need for specifications is most likely to appear during performance of install activities. Examples of activities in which this occurred include installing drive shafts, differentials, brake slave cylinders, track road wheels, drive sprockets, carburetors, starters, spark plugs, valve covers, and intake and exhaust manifolds.

In performing adjust activities, lack of awareness was not the most frequent cause of specification errors. When apparent lack of awareness of specifications did occur, it was observed most often in adjusting wheel bearings, engine timing, and engine idling speed.

2. Mechanic errors in applying specifications correctly. In this case the mechanic goes through the motions and appears to believe he is correctly applying the specifications. This type of behavior appeared most frequently in performing adjust activities. In one type of instance, the mechanic remembers or obtains the correct specifications but, in the process of applying them, recalls them incorrectly or interchanges specifications intended for different parts of the component. In these instances, mechanics appear unaware that they have confused or transformed these specifications. Without doublechecking or some other type of checkout procedure, these errors go undetected. Mechanics commonly fail to perform these types of checks.

A second type of error made in applying specifications during adjust activities is the failure to recognize the condition the equipment must be in to enable the specifications to be correctly applied. Examples of this

type of error include torquing wheel bearings without jacking up the vehicle, adjusting valve tappet clearance without running the engine, and adjusting timing on a cold engine.

3. Errors based on local shop standards and gaps in shop resources.

The third, and probably most influential source of specification error is attributable to the informal policies and the resources which govern the way maintenance is performed in the local shop. Observations revealed that, in most shops, the mechanic performing the task was the sole judge of when the work was successfully completed. This creates a climate in which the mechanic is expected to make do with what he knows and with what he has at hand. As a result, mechanics come to rely on their knowledge of how they, or coworkers, previously performed the task as the standard for how the task should be performed. The tools they know best and have at hand are common tools such as hammers, screwdrivers, chisels, crescent and other types of small wrenches, pry bars, and sledge hammers. Specifications generally require use of a special tool or test equipment which, in many instances, is not available. Performing without using specifications, or without even recognizing the need for them, becomes standard procedure. If the mechanic needs information, he does not use the TM because specifications and standards contained in it are simply not relevant to the way maintenance is performed in his shop.

Use of information sources. Data in Table 2 indicate that information was sought by 27% of the 102 mechanics performing assignments requiring use of technical specifications. Furthermore, other personnel were more likely to be used as a source of this information (21%) than were TM (13%). Consistent with the use of information sources in general, specification information was sought primarily by personnel who had little or no previous experience in performing the assignment. Those who used specification information sources were about as likely to make specification errors as those who didn't seek this type of information (44% versus 56%, respectively). Interpretation of these findings has been presented above under "Contributing causes."

Table 2
TYPES OF INFORMATION SOUGHT 1 OR MORE TIMES
BY SOURCE
(% of Mechanics)

Information Type	Source Used		
	Person	TM	Either Person or TM
Identification/location of component. (Where is it?)	5	3	6
Procedural directions. (What do I do?)	7	6	12
Technique (How do I do it?)	20	6	23
Standards/Specifications (Do I need specs? What are they?)			
Task performed requires special tools/tech. specs.	21	13	27
No special tools/tech. specs. required in task performed	7	0	7

Technique Errors

Description. Technique errors considered here are those not directly involved in applying technical specifications. Most of these technique errors are reflected in improper use of common tools and either failure to use, or improper use of, special tools such as road wheel lifters and bearing extractors. Examples of these errors include failure to use supporting slings or some substitute when removing a differential from a vehicle, use of a hammer and screwdriver to bend tabs on locknut washers, using hammer and chisel as a substitute for wrenches, and using a sledge hammer to remove hydraulic jacks wedged under road wheel arms.

Probability of occurrence. The probability of occurrence of these errors is about the same for each of the four types of maintenance activities. Using the data in Figure 9 as a basis, we would expect mechanics to make one or more technique errors during performance in about 33 out of every 100 work assignments. Serviceability of the equipment would be impaired by uncorrected technique errors in about 11 of every 100 maintenance assignments.

Use of improper techniques was not scored as serious uncorrected errors unless they resulted in damage to serviceability or safety of the equipment. Thus, the difference between 33% process errors and 11% serious uncorrected technique errors does not mean that 22% of the mechanics discovered and corrected their technique errors; it only means that their errors did not have serious consequences for the condition of the equipment.

Contributing causes. As stated earlier, the tools mechanics know best are the common tools they have at hand such as hammers, screwdrivers, chisels, crescent and other types of small wrenches, pry bars, and sledge hammers. These are the tools they are most likely to use in undertaking almost any assignment. When the component being worked on is rugged and can stand the punishment, mechanic technique errors are not likely to cause serious damage. The problem is apparent failure to recognize when damage is likely and lack of knowledge of more appropriate techniques to use in these cases. Technique errors frequently occur as spur-of-the-moment solutions created by a mechanic to make do with what he has at hand and complete the assignment. For example, a mechanic can't get a fuel line connection to align properly, so he wraps it with electrical tape in an effort to prevent leaking. Or, he can't get a wheel bearing to slip into position on the spindle, so he gets a hammer and hammers it into position. In addition to generally being the sole judge of the adequacy of their work, mechanics do not routinely perform checkouts on their work. The absence of corrective feedback means that a mechanic frequently never learns what the expected or actual consequences were of his make-do techniques.

Use of information sources. Technique information was sought by 23% of the 236 mechanics (Table 2). Most of these mechanics went to other personnel for this information (20%) rather than to a TM (6%). TM were generally of little help to the mechanic with a technique question. In some cases this was because the TM identified only the step to be performed, not how it could be accomplished. In most cases the mechanic knew the step he should perform. His problem was that he couldn't figure out why his efforts to perform the step were not succeeding.

Procedural Errors

Description. Procedural errors reflect errors made by performing steps out of sequence when a particular sequence is required, errors made by omitting steps or parts required, and errors made by using an incorrect part. For example, errors of sequence include trying to remove a carburetor before disconnecting the fuel line, attempting to install the radiator fan after the radiator has been installed, and attempting to adjust blower belts without first loosening the adjusting nut. Errors of omission are most likely to occur during install activities and include such things as failure to use lock washers, failure to install the accelerator return spring, and failure to install the required number of mounting bolts or fasteners. Errors involving incorrect parts include installing a secondary oil filter in the primary oil filter case, installing left-threaded studs in place of right-threaded wheel mounting studs, and installing damaged parts, for example, bearings, seals, gaskets, and studs with stripped threads, instead of replacing them.

Probability of occurrence. The probability of occurrence of procedural errors is essentially the same as the probability for technique errors. Using the estimates based on all four of the activities, we would expect about 33 out of every 100 work assignments to contain one or more procedural process errors (Figure 9). Serviceability of the equipment would be impaired by uncorrected procedural errors in about 13 of every 100 maintenance assignments. Unlike technique errors, the difference between the 33% who made one or more procedural process errors and the 13% who had serious, uncorrected errors does tend to reflect discovery and correction of procedural errors.

Contributing causes. As described earlier, mechanics use the equipment to direct and guide them in performing maintenance activities. They study the equipment to identify what to do next and observe what happens when they attempt to carry out that action or step. If what they observe happening meets their expectations, they proceed to identify and perform the next step. If the action doesn't produce the result expected, they stop and

attempt to figure out what went wrong. Thus, design of equipment is more important than manuals in directing and guiding what steps or actions are undertaken. Parts that are designed for different functions, or different locations, but are similar in size and shape are likely to be interchanged by mistake. Installation of separate "accessory" parts, such as lock washers, and safety wiring of certain bolts/nuts is likely to be omitted. Since errors of this type do not prevent the mechanic from "completing" the installation, he is likely either not to be aware of his omission or to consider it unimportant. These errors continue to occur when his work is not checked against maintenance standards and when he is not provided with corrective feedback.

Use of information sources. Procedural information was sought by only 12% of the 236 mechanics (Table 2). Those who sought this type of information were about as likely to obtain it from other personnel (7%) as from a TM (6%). The low probability of this type of information being sought is consistent with the observation that mechanics generally identified "next steps" by studying the equipment. Those who used information sources to obtain procedural information were just as likely to make errors as those who didn't seek this type of information.

A related type of information that was sought least frequently of all types concerned identification of parts and finding their location on the equipment. Only 6% of the mechanics sought this type of information (Table 2). Most of these mechanics sought this information by asking another mechanic (5%) and only 3% looked for it in a TM.

Errors in General Mechanical Practices

Description. Errors in mechanical practices are a special kind of technique error which reflect sloppy or unsafe practices as opposed to improper use of tools. Examples of these errors include failure to use jack stands, draining oil or radiator fluids onto the floor, and leaving fuel cell and transmission openings exposed to rain and dust after removal of fuel pump and oil filters.

Probability of occurrence. The data in Figure 9 suggest that errors of this type can be observed in about 10 out of every 100 maintenance assignments. Serviceability of the equipment was considered impaired in only 1% of the observations. The difference between 10% process errors and 1% serious errors does not mean that the process errors were corrected. It simply means that these process errors did not usually result in damage to the equipment. These errors, unlike the other types, are more likely to pose a threat to the safety of the mechanics than to the serviceability of the equipment. Injury to mechanics as a result of these errors was not observed. However, slippery floors and failure to use jack stands are certainly conditions favoring occurrence of serious injury. These observations suggest that these conditions are present in about 10 out of every 100 assignments.

Contributing causes. The chief contributing cause again appears to be the absence of checking and correcting that, if given, will define performance standards for the personnel and help them learn how maintenance activities should be performed.

Use of information sources. No information seeking was identified that was directed specifically to anticipating or finding ways to deal with these errors.

Final Checkout Errors

Description. Final checkouts refer to the operational checks a mechanic is expected to make as the last action after completing many install or adjust assignments. These final checkouts include such things as road testing a vehicle to see if brakes function properly after adjusting or bleeding brakes, bringing the engine to operating temperature to check for leaks after installing a radiator and hoses, and running the engine to check generator output after installing a new generator.

The most frequent final checkout error was simply failure to conduct a checkout. When checkouts were made, three types of errors were observed. These were failure to observe the necessary checkout conditions, incomplete checkouts, and errors in interpreting results of the checkout. An example

of errors due to failure to observe conditions necessary for performing the checkout is checking for leaks in radiator hose connections without operating the engine or bringing it to operating temperature. Incomplete checkouts consist of initiating a checkout but doing only part of it. An example of an incomplete checkout is checking engine operation after adjusting valves but failing to check for oil leaks around the valve cover gasket. Errors in interpreting results of the checkout may occur whether or not the checkout has been performed correctly. However, examples from the observations suggest that the mechanic's conclusions are more likely to be in error when the checkout has not been performed properly. For example, a mechanic completes a brake adjustment, rotates the wheel to check for brake shoe drag, and decides the adjustment is adequate even though the wheel still rotates freely with the brake pedal depressed as far as it will go. The mechanic's error in interpreting this phase of the checkout remains undetected, and hence uncorrected, since he failed to road test the vehicle.

Probability of occurrence. The figures in Table 3 suggest that 66 out of every 100 work assignments will not be adequately checked out when such checkouts are possible. Based on these results, supervisors could expect that in 45 out of every 100 work assignments requiring checkouts, mechanics will not attempt to perform a checkout. In an additional 21 out of every 100 such assignments, checkouts will be initiated but not completed correctly. Experienced mechanics are no more likely to perform checkouts correctly than are inexperienced mechanics.

Contributing causes. Most of the contributing causes discussed in relation to specification errors appear to apply equally well to causes underlying final checkout errors. Informal operating practices in local shops do not require or encourage mechanics to check out their work. The mechanic is generally the sole judge of whether or not the work is successfully completed. He does not receive feedback and corrective guidance from personnel who are well versed in maintenance standards. As a result, the local climate is for the mechanic to make do with what he knows and has at hand. "Completing" work assignments without performing checkouts becomes "the way it's done" in his shop.

Table 3

**PERFORMANCE OF FINAL
OPERATIONAL CHECKOUTS***

Checkout performance	% of mechanics (N = 173)
Made correctly	34
Made incorrectly	21
Not performed	45
Total	100%

* Analysis provided by D. L. Schurman, A.J. Porache and R.P. Joyce, Applied Science Associates, Inc.

Use of information sources. No information seeking was identified that was directed specifically to performance of final checkouts.

SUMMARY

This report has provided information necessary to employ scarce supervisory resources more effectively within the organizational level of maintenance. This information, combined with a commitment to initiate a higher level of quality control, can provide a basis for operational units to improve both mechanical maintenance and skill development of their personnel.

APPENDIX Example of An Observational Recording

TASK NAME: Remove/Install/Adjust Wheel Bearing, M151

O #: 066 MOS/DUTY: 63C-10 DATE: 1-18-79

PRIOR TASK EXPERIENCE: 2 RECENCY: 10 months

COMPLETION ERRORS: 17, 20, 23, 27 CHECKOUT: Possible, not made

OBSERVED PERFORMANCE:

1. Removes tire and rim on jacked up right front wheel
2. Removes lifting eye
3. Tries to remove brake drum without backing brake shoes
4. Looks over situation, considers backing off brake shoes but doesn't
5. Removes spindle nut
6. Pushes spindle back
7. Tries to remove drum again
8. Fools with hub and looks situation over
9. Keeps trying to push spindle out of backing plate
10. Sits back and looks situation over again
11. Another mechanic tells to back off brake shoes but S ignores
12. Keeps yanking on drum until he gets to point that he realizes he
must back off brake shoes
13. Backs off brake shoes
14. Removes hub
15. Removes spindle housing
16. Checks outer bearing
17. Tries to pry off bearing with screwdriver and fails
18. Looks at how to get inner bearing out
19. Tries to push spindle out from front without unbolting U-joint
20. Tries to remove inner bearing by prying out front - gives up
21. Repeats steps #17-20
22. Repeats steps #17-20
23. Packs outer bearing on spindle by hand - but lightly
24. Stuffs grease inside spindle housing
25. Puts hub on and rotates a while

APPENDIX (continued)

26. Puts spindle and hub on
27. Puts spindle nut on and tightens
28. Rotates hub to check tightness (fairly tight) - does not measure torque
29. Backs off nut to find cotter pin hole
30. Backs off again
31. Does not check wobble (too loose)
32. Gets oversize cotter pin
33. Puts in cotter pin and cuts off
34. Remounts tire and wheel
35. Lets down wheel