THE EFFECTS OF EQUIPMENT AGE ON MISSION-CRITICAL FAILURE RATES

A Study of M1 Tanks

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SUMMARY

> Without a significant effort to increase resources devoted to recapitalization of weapon systems, the force structure will not only continue to age but, perhaps more significantly, become operationally and technologically obsolete.
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> *Quadrennial Defense Review Report*, 2001, p. 47

Aging equipment has become a key concern of Army leaders striving to maintain high operational readiness. Army leaders anticipate that equipment age will pose a continually increasing challenge over the lengthy period in which current equipment is expected to remain in the Army's fleet, anticipated until about 2030 in some cases, as it develops and fully fields its next generation of forces termed the future force. In response, the Army has initiated a recapitalization (RECAP) program to rebuild and/or upgrade selected systems, such that combat capabilities are maintained and maintenance costs are kept affordable.[1] To date, the Army plans to rebuild or upgrade 17 systems—including the M1 Abrams, M2 Bradley Fighting Vehicle, M88 Recovery Vehicle, and other systems that are expected to remain in the inventory for the next 15 to 20 years (Brownlee and Keane, 2002; Army Recapitalization Management, 2003). These modernization plans continue to evolve, however. To help determine the scale of

[1]Rebuilding consists of efforts to restore a system to like-new condition. Upgrading is adding components (or replacing old components with new ones) that increase a system's warfighting capability (Gourley, 2001).

RECAP required to maintain the desired level of operational readiness capability, and to facilitate RECAP program design, statistical analyses of the relationship between age and Army equipment failures are needed.

This report describes a RAND Arroyo Center study, sponsored by the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (OASA[ALT]), on the impact of age on the M1 Abrams mission-critical failure rate. The M1 Abrams is of particular interest because it is often considered the centerpiece of the Army's heavy ground forces, because it has a high average fleet age that will continue to advance, and because it is scheduled to remain a key part of the force for as many as 30 more years. Consequently, it has been one of the key systems being targeted by the RECAP program.

RESEARCH QUESTIONS

The four research questions in this study are as follows:

1. What is the relationship between age and the M1 Abrams mission-critical failure rate?[2]
2. How is the M1 failure rate related to other factors, such as usage and location-specific factors?
3. If there is a significant relationship between age and the M1 Abrams mission-critical failure rate, which of the various M1 subsystems and individual parts generate this relationship, and to what degree do they do so?
4. How can statistical models of such relationships inform RECAP decisions and planning?

Subsequent studies will address the same questions for other critical Army ground systems.

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[2]A mission-critical failure is defined in this study as one that makes an item not mission capable, as indicated by the item's technical manual and subsequently reported by its owning unit. Mission-critical failures are also called *deadlining events*.

STUDY DESIGN

To address the research questions, we conducted two "substudies" at the individual tank level of analysis. In substudy 1 (the *Tank Study*) we assessed the impact of age, location, and usage on individual tank failures. In substudy 2 (the *Subsystem Study*) we assessed the impact of tank age, location, and usage on tank subsystem failures. Subsystems included actual subsystems, such as fire control, as well as part technology groups, such as basic hardware. As an additional segment of the Subsystem Study, we assessed the impact of tank age, location, and usage on tank *part* failures, where parts (subsystem components such as transmissions and pumps) were placed into price categories ranging from low to very high. The samples for the two substudies included 1,567 tanks and 1,480 tanks, respectively,[3] which includes the tanks in the Army's six active heavy divisions distributed across what we categorized as six different geographic areas: Germany, Georgia, Korea, Kansas, Colorado, and Texas.

The age, location, usage, and failure data came from Army maintenance database extracts from April 1999 through January 2001.[4] Our primary analytical techniques included imputation of missing data and negative binomial regression. It should be noted that data on the maintenance history of each tank prior to the beginning of the study period were not available. Hence, only the ages of the tanks themselves, and not their components, were known.

RESULTS

The study provides preliminary support for the hypothesis that age is a significant predictor of M1 failures, as are usage and location. The models suggest that M1 age has a positive log-linear effect that is consistent with a 5 ± 2 percent increase in tank failures per year of age. For a given location, usage, and time period, this equates to a 14-

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[3]The sample in the Subsystem Study included fewer tanks because we lacked complete data on 4th Infantry Division M1A2 subsystem failures.

[4]Failure data came from Standard Army Maintenance System-2 (SAMS-2) aho01i and aho02i files archived in the Integrated Logistics Analysis Program (ILAP), and age, location, and usage data come from The Army Maintenance Management System (TAMMS) Equipment Database (TEDB). Unit price data for tank parts came from Federal Logistics (FedLog) database extracts for January 2003.

year-old tank having about double the expected failures of a new tank. This conclusion only applies to the first 14 years of a tank's life, since most tanks in the study were 14 years old or younger at the time of the study. (Only two tanks in the dataset were 15 years old.) The conclusion may or may not hold beyond that point; this can be determined as the Army's tank fleet continues to age. In the meantime, it is risky to assume that this compound annual growth rate in failures applies beyond the age range of our dataset.

Usage appears to have a log-quadratic effect on the mean failures of tanks; this implies that as tank usage during a year increases, the expected failures increase, but the rate of increase continually slows as usage increases (in the range of peacetime, home-station usage). Again, this conclusion is only valid within the range of the data—up to approximately 3,000 kilometers in peacetime operations. At some point the usage effect may become linear, with each one-kilometer increase in usage producing the same increase in expected failures.

The magnitude and shape of the observed effects—particularly the relationship between age and failures—differ across tank subsystems. The electrical, hardware, hydraulic, and main gun subsystems experienced larger *absolute* failure rate increases due to aging than the chassis, power train, and fire control subsystems. The chassis, hardware, hydraulic, and main gun subsystems experienced the greatest *relative* increases due to aging. Because the electrical subsystem had a high initial (age-0) failure rate, the relative increase in its failure rate was low, despite a high absolute increase. Because the chassis subsystem had a low initial failure rate, the relative increase in its failure rate was high, despite a low absolute increase. Also, for some subsystems the effect of age diminished or disappeared after tanks reached a certain age, which is probably an indication that the age was beyond the normal wear point for the subsystem's components. The point at which failures no longer increase with age for a subsystem (or part) or actually start to decrease reflects that point at which the peak wearout age region has been passed and sufficient fleet renewal for the subsystem (or part) has occurred to reduce the effective age of the fleet with respect to that subsystem (or part).

For the fire control subsystem, our data suggest an aging effect but also a possible effect with respect to tank variant. (Fully isolating these two effects was not possible, since age and tank variant are confounded.) M1A2s, which are younger than M1A1s, have different types of fire control components than M1A1s—in particular, digital electronic line replaceable units (LRUs), rather than analog LRUs. The data suggest that the like-new failure rate of M1A2 fire control components is higher than that of fire control components in relatively young M1A1s.

Supplementary analyses of subsystem part failures and the unit prices of those parts provided additional information about the drivers of aging effects. Specifically, aging effects tended to be stronger for low-priced parts than for high-priced parts.

Although not a focus of this study, the effect of location is noteworthy. Some locations had significantly more tank failures than did others, after controlling for usage and age. This could be due to different maintenance practices, climate, terrain, training plans, and failure-reporting practices.

IMPLICATIONS

Consistent with private industry fleet management principles, Army leaders have long believed that older tanks have higher failure rates than newer ones, which increases maintenance demands and stresses operational readiness. However, supporting statistical evidence has been lacking. This study provides such evidence, demonstrating that increasing age, after accounting for usage and location effects, tends to raise M1 failure rates (given the current Army maintenance regime). Although the study is cross-sectional (incorporating one year of data from tanks), its findings—and the results of sensitivity analyses involving additional data and tests—provide initial quantitative support for several conclusions. Specifically, it is reasonable to conclude that, without modernization, time (or age) will pose a threat to operational readiness and increase the demand on resources.

Another important finding is that age is harder on some subsystems than on others. Moreover, within subsystems, age has different effects on different components. Knowledge of these patterns may help RECAP planners determine which subsystems and components should be rebuilt and which should receive higher priority in such efforts. Further, the study indicates which subsystems and components are likely to drive the failure rate of new tanks—specifically, fire control, electrical, and power train; whether new or old, these components constitute reliability "problems." This information suggests where upgrade initiatives such as engineering redesign might have the biggest impact.

Further exploration of the source of age effects on the Abrams failure rate yields valuable insights into the aging problem. Much of the age effect tends to result from what are, in the Abrams, relatively low-cost components, so the age effect on operations and maintenance cost (the budget account used to pay for spare parts) is likely to be less than its effect on readiness and workload. These components are typically simple parts that have dominant failure modes associated with wear-and-tear. The expensive parts, in contrast, tend to be more complex, with many different failure modes. Increased component failures increase the maintenance workload burden. Since Army maintainers are not paid according to the amount of maintenance they perform and do not receive overtime, this does not affect the Army's cost structure. Rather, it can affect maintainer quality of life when the workload necessary to maintain operational readiness increases substantially.

Additionally, there are potential implications for force structure and future operational readiness. Once tank age reaches a certain point, the maintenance system may no longer be able to supply a satisfactory level of operational readiness—even with workarounds such as controlled exchange, necessitating replacement or substantial rebuild or acceptance of lower readiness possibly combined with increased maintenance capacity. There is some indication that a portion of the active Army's tank fleet has already reached this point, causing isolated M1A1 operational readiness problems. For example, Fort Riley units, with the oldest tanks in the Army's active inventory, are the only active units that consistently struggle to meet the Army's operational readiness rate goal for tanks.[5] At the Army's National Training Center (NTC), tank battalions employing relatively old M1A1s (both NTC-owned and from home stations) averaged just 74

[5]From 1999 to 2001, Fort Riley M1A1 operational readiness averaged 88.05 percent, while the active force M1A1 average was 90.75 percent, based on monthly readiness reports extracted from the Logistics Information Database.

percent operational readiness over the course of rotational training events from fiscal years 1999 through 2001; 4 of the 22 battalions for which data are available achieved less than 70 percent, a figure often considered the breakpoint for combat effectiveness.[6] This contrasts with an average of 83 percent for battalions with relatively new M1A2s. Repair time for the two groups was similar, with a difference in failure rates accounting for the difference in operational readiness rate. Thus, for the Abrams fleet, age most likely produces gradual workload increases, possibly resulting in decreasing soldier quality of life and declining operational readiness, and it generates a buildup of deferred financial cost that emerges in the form of programs such as RECAP.

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[6]The NTC metrics are based on manually collected data provided by NTC observer-controllers (OC) to one of the authors. Each day, OCs collocated with tank platoons report the operational readiness status and failure information to the Forward Support Battalion Support Operations Officer OC, who records the information.