Field Reliability Versus Predicted Reliability: An Analysis of Root Causes for the Difference

Phillip E. Miller; Air Force Institute of Technology, Dayton
Richard I. Moore; Air Force Institute of Technology, Dayton

Key Words: Reliability analysis, reliability—field, reliability management, reliability—predicted.

Summary and Conclusions

The significant difference between predicted reliability and actual reliability of fielded systems—what we have termed the "reliability delta"—has been a long-standing problem in reliability engineering. An extensive literature review was conducted to identify root causes contributing to this difference. In addition, SAS analysis of data collected in a 1988 study yielded interesting results. This research asked 38 reliability experts from the Department of Defense and Industry to identify and rank order factors which potentially contributed to the reliability delta. Total Quality Management (TQM) tools were used to analyze the relationships among and impact of key variances on the reliability prediction process and explain apparent differences between the DoD and Industry perspectives.

The literature review identified eleven factors as possible causes of the reliability delta; however, only six were noted as being significant by the experts. The six factors identified were: problems with data collection, assumptions underlying use of prediction techniques, lack of understanding of the operational environment, problems with manufacturing processes, short-term management focus, and design-related problems. Each of these factors was evaluated from both DoD and Industry perspectives. Although the six factors were identified by both groups, the rank order of the importance of these factors was virtually reversed between DoD and Industry personnel. The contrasting priorities may in part explain the focus of management efforts of one group on factors which are considered less important by the other. The final section highlights some of the logistics impacts of the reliability delta.

1. Introduction

Over the years, the reliability of fielded weapon systems has consistently been less than predicted during system development. In a 1988 study, the General Accounting Office reported the ratio of predicted time between failure (MTBF) to demonstrated MTBF in B-1B equipment ranged from 7:1 to 20:1 (Ref. 14). Although these ratios may seem excessively high, they are consistent with the results of studies accomplished over ten years ago. Thus, despite the emphasis on reliability engineering over the past decade, reliability estimates still lag far behind demonstrated reliability. This inability to relate laboratory to field reliability causes the reliability delta and has a significant impact on system operational readiness and life cycle costs. While higher than predicted reliability would be favorable, the actual reliability is almost always lower than predicted. Nonetheless, the predicted reliability of a weapon system is often the best estimate available and provides the cornerstone of many logistics decisions including maintenance planning, spares parts provisioning, as well as acquisition of test sets and specialized equipment. As a result, a better understanding of causes of the reliability delta is important to all logistics issues. Determining the root cause of the reliability delta is the first step in improving reliability estimates. This research addressed four questions:

1. What factors contribute to the reliability delta?
2. How are these factors interrelated?
3. Can we use these causal factors and interrelationships to our advantage to reduce the reliability delta?
4. Do the Department of Defense and Industry have differing views concerning the significance of these factors on the reliability delta?

2. Literature Review

In the early years of reliability engineering, RCA studied the topic and presented their findings in the August 1955 Proceedings of the Conference on the Reliability of Military Electronic Equipment. Their study postulated ten major conclusions related to reliability and, despite the passage of nearly 34 years, most still apply. The following list provides examples of several of the timeless reliability axioms which were proposed:

- Reliability is a systems problem;
- Reliability requires organization;
- Reliability requires adequate logistics support;
- Reliability takes time;
- Reliability requires military and industry teamwork (RCA, 1956).

Lloyd and Lipow (Ref. 7) attribute the majority of problems in reliability to two major factors: the complexity of concurrent system development and budget restrictions. These ideas were reinforced by an Air Force Logistics Command study in the early 1980s which revealed that part failures accounted for at least twenty percent of the Air Force budget. The study was one of the first to link increased reliability with significantly decreased spare requirements (Ref. 4).

2.1 The Reliability Delta

The inability to relate predicted and field reliability has proven to be extremely costly. It has been shown that the "inaccurate predictions of reliability characteristics may result in non-optimum allocation of program resources, and, in turn, low levels of operational readiness" (Ref. 6). As a result, many researchers have studied the factors which contribute to the reliability delta. A solution to the reliability delta is possible if, and only if, key factors can be identified, properly measured, and subsequently controlled.

Kern (Ref. 5) studied failures in avionics equipment from 10 different Air Force aircraft and attributed the reliability delta to definition, operational, and environmental factors. Definitional
factors are semantic-based and are caused primarily by differences in failure criteria definitions used by AFLC and the engineering community. Operational factors include the impact on reliability resulting from maintenance, handling, and equipment use. Finally, environmental factors relate to the practice of using a single factor regardless of aircraft type. It should be obvious that the operational environments of fighter, bomber, and transport aircraft are substantially different.

Muglia analyzed MTBF prediction data from Hoffman Electronics Corporation’s 13-year experience with Tactical Air Navigation systems. One significant finding of the study was that the estimated MTBF can vary as much as 6.5 times the specified. Muglia attributed the variance to the differing methods the DoD and contractors used to estimate the MTBF. Furthermore, the study highlighted the potential for reliability degradation resulting from an overemphasis on cost and schedule. He indicated that "Management must allow time and funds for testing, repair, and design correction where necessary to eliminate design, manufacturing, and testing/handling deficiencies" (Ref. 12).

Lynch and Phaller (Ref. 9) blamed the difference on certain assumptions inherent in the MIL-HDBK-217 prediction models. Part-level assumptions—related to the quality of design/construction and to production process control procedures—apparently significantly affected the reliability delta.

In 1974, The Joint Logistics Command sponsored a Reliability Test Committee which marshalled the combined skill of DoD and industry experts to increase knowledge about the causes of the reliability delta in electronic equipment. The group’s findings can be classified into four categories:

1. Differences in failure definitions.
2. Poor definition of the operational environment.
3. Misinterpretation of test plan results.
4. Inadequate fault isolation techniques. (Ref. 1)

In another study, Shelley and Stovall (Ref. 13) evaluated the relationship between the field and laboratory MTBFs. Their first conclusion was based on the relationship between sample size and variance reduction. The accuracy of the estimate improves when reducing potential for sampling error. They also introduced the idea of the role of the human element in the reliability difference equation. A second reason cited for the reliability delta was the natural tendency of field personnel to count discrepancies as failures unless it is proved conclusively that there was no failure. In the laboratory, however, there is a strong inclination to exclude a discrepancy unless it is apparent that it is a failure as contractually defined.

Balaban (Ref. 2) identified the limitation associated with field data collection systems and attributed the reliability differences to three areas: representativeness of the laboratory environment, accuracy of specifications, and inherent variability of operating systems. First, even though system predictions are based on the best data available, the analyst works in an environment that limits the accuracy of any reliability estimate. Predictions must incorporate the effects of “moving targets” such as: design changes; the use of non-representative hardware or software interfaces; inadequate test equipment, manuals, or a lack of appropriately qualified operators or support personnel. Balaban indicated there are always trade-offs between test length, test timing, and test realism which limit the accuracy or quality of the initial reliability estimate. (Ref. 8) Secondly, improper assumptions concerning the physical operating environment, including usage assumptions and support concepts, are understandably significant issues.

Finally, Balaban concluded that, despite our attempts to develop perfect estimates, similar hardware operated under supposedly similar conditions can exhibit widely varying reliability characteristics. Lynch and O’Berry (Ref. 8) collected over two years’ data on 500 systems deployed at 10 operational sites. They concluded that the most significant factor affecting field reliability was the maintenance/logistics support-related environment including the actions and interactions of the key elements of personnel, management, equipment, and spares. In addition, they discovered that only 20 percent of the field reliability problems were hardware-related.

Finally, MacDiarmid (Ref. 11) examined several studies and concluded that the terms operational and contract reliability were generally defined differently and served totally different purposes. He contended that we should recognize that the contractual and operational reliability are fundamentally different terms in concept, in measurement method, and in usage. He stressed that the main point was not necessarily recognizing the difference but attempting to establish a relationship between the two reliability parameters.

2.2 Literature Review Summary

The reliability delta—the difference between predicted and field reliability—can be attributed to many factors, only some of which are controllable. A summary of the major contributing factors and their associated references are presented in Table 1.

<table>
<thead>
<tr>
<th>Major Contributing Factor</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitional</td>
<td>Anderson, MacDiarmid, Kern, Shelly</td>
</tr>
<tr>
<td>Operational</td>
<td>Anderson, Balaban, Kern, MacDiarmid</td>
</tr>
<tr>
<td>Environmental</td>
<td>Anderson, Lynch &amp; O'Berry, Kern</td>
</tr>
<tr>
<td>Predictions Techniques/Assumptions</td>
<td>Balaban, Lynch &amp; Phaller, Muglia</td>
</tr>
<tr>
<td>Test Plan Results</td>
<td>Anderson</td>
</tr>
<tr>
<td>Fault Isolation Techniques</td>
<td>Anderson</td>
</tr>
<tr>
<td>Analysis &amp; Test Weaknesses</td>
<td>Balaban</td>
</tr>
<tr>
<td>Improper Assumptions</td>
<td>Balaban</td>
</tr>
<tr>
<td>Reliability Measurement Methods</td>
<td>MacDiarmid</td>
</tr>
<tr>
<td>Management Support</td>
<td>Muglia</td>
</tr>
<tr>
<td>Statistical Variability</td>
<td>Shelly &amp; Stovall</td>
</tr>
<tr>
<td>Human Performance</td>
<td>Shelly &amp; Stovall</td>
</tr>
</tbody>
</table>
The data analyzed in this study were gathered by Captain Katherine Ma (Ref. 10) as a part of her 1988 thesis at the Air Force Institute of Technology. A questionnaire was developed which consisted entirely of open-ended questions asking reliability experts to identify the major factors contributing to the reliability delta. For the purpose of this study a reliability expert was considered to be anyone who had extensive experience in working reliability issues in either government or industry. The respondents were asked to identify major factors contributing to the reliability delta. After all interviews were completed, a composite list of significant factors was developed by adding factors not identified in the literature review. This process combined several of the factors resulting in a list of 11 potential causes of the reliability delta. Respondents were asked to rank order these 11 factors. Since the research objective required finding and analyzing the most significant factors, the number of individuals who identified each factors was tallied. Of the eleven major factors identified as possible causes of the reliability difference, only six were mentioned by a sufficient number of individuals to be statistically significant (See Figure 1). Three of these factors—data collection problems, use of prediction techniques/assumptions, and an understanding of the operational environment—were identified by over 65 percent of the experts as having a major impact. Over 50 percent of the respondents identified problems with manufacturing processes as a major contributor. The final two topics, top management commitment and design-related problems, were identified by 37 percent of the experts. The remaining factors were identified by less than 15 percent of the respondents and were not considered as significant contributors to the reliability delta.

![Figure 1. Factors Contributing to the Reliability Delta](image)

### 4. Description of Major Factors

#### 4.1 Data Accuracy
Most experts felt that the majority of data problems were concentrated in the areas of data definition and data collection. Concerning data definition, most respondents mentioned the difficulty associated with the classification of failures and scoring procedures. Definitional subtleties complicate the problem by requiring personnel who report failures to distinguish between terms such as: relevant and nonrelevant failures; failure and a critical failure, contractual versus operational failures, inherent and induced failures, and hardware versus software failures.

Most of the interviewees considered the current DoD data collection system as inaccurate, untimely, and incomplete. They also mentioned that there is an apparent lack of incentive for accurate classification of failures by the data collectors. In addition, most of the respondents felt that the current data collection system is used as a manhour accounting system to ensure the documentation of a contractor's work, rather than a system to collect accurate reliability data.

#### 4.2 Prediction Techniques
Most experts suggested that the prediction techniques accounted for the bulk of the difference between field and predicted reliability. About half of the experts attributed the prediction problems to the techniques and assumptions used in MIL-HDBK-217. In addition, the experts indicated the predictors specified by the handbook were nonrepresentative of the operational environment. Other problems with the prediction technique were related to the improper application of reliability models.

#### 4.3 Environmental Factors
Most of the environmental problems were attributed to a lack of knowledge and misinterpretation of the operational environment. Some experts felt that the inappropriate selection of design-related factors in the areas of producibility and quality. The experts suggested that a robust system design could overcome the majority of producibility problems. Quality, on the other hand, is also contractor-dependent in that the experts believed quality of the product depends greatly on whether the contractor supports a total quality management program.

#### 4.4 Manufacturing Processes
Manufacturing processes can greatly affect field reliability. The primary problems can be classified in the areas of producibility and quality. The experts suggested that a robust system design could overcome the majority of producibility problems. Quality, on the other hand, is also contractor-dependent in that the experts believed quality of the product depends greatly on whether the contractor supports a total quality management program.

#### 4.5 Design-related Factors
The experts felt that the inappropriate selection of parts and components contributed to the reliability delta. A final design-related problem is based on changes in design technology. Computer-aided Design (CAD)—while greatly decreasing design lead time—does not explicitly consider reliability parameters.

#### 4.6 Short-Term Management Focus
Experts who identified management as being one of the major contributors to the reliability delta ranked it first or second in importance. They indicated most
managers were more concerned with short-term benefits than long-term gains. Consequently, reliability efforts were often underfunded since reliability is a long-term undertaking. Ralph Evans states that "short-term management is the major bottleneck to achieving the levels of reliability that are normally desired by users" (Ref. 3).

5. Analysis of the Major Factors

During the interviews, experts were asked to rank in order of importance the factors contributing to the reliability delta. The responses were weighted by a factor ranging from a "10" (for the top-rated factor) to a "5" (for the lowest or sixth factor). Thus, for each of the six significant factors, a composite rating was calculated based on each expert's rankings.

Two data analysis problems existed since each of the factors was suggested by a different number of experts, each having a different opinion about the relative rank order of the factors. The first problem - the number of experts - was partially addressed by eliminating any factor that was not mentioned by at least a third of those surveyed. The second problem - establishing a composite ranking - was overcome by averaging the weighted rank orders. Figure 2 shows the relative rankings for the six major factors the experts identified as being key contributors to the reliability delta.

![Figure 2. Rank Order Means](image)

The first observation is that the rank order average for each of these six factors is extremely high. The lowest any of these factors were ranked by the experts was a six with most of the ranks being rated eight or higher. Thus, the overall average for the six factors ranged from a low of 7.8 to a high of 9.3. The mean rating across all categories for both groups was 8.56. There was no statistically significant difference between the two group means when the six major factors were ranked using Statistical Analysis Software (SAS).

Although the group means were statistically identical, the relative position of each factor was almost reversed when comparing the rankings of DoD and industry experts. DoD experts ranked top management commitment and understanding of the operational environment as the top two contributing factors. Data problems and use of prediction techniques were ranked third and fourth, respectively. For the DoD experts, the lowest rated factors were design-related problems and problems with manufacturing processes.

In contrast, industry experts ranked problems with data and design-related problems as being tied for first, followed closely by manufacturing process problems. All three of these factors were ranked higher (on the average) than any of the DoD factor rank means. The industry's fourth-ranked factor, use of prediction techniques, had the same relative position in both groups and also had no statistical difference between the group means. The two factors identified by the industry experts were top management commitment and understanding of the operational environment. These two factors were ranked as low or lower (on the average) than any of the DoD ranked factors.

It is interesting to observe that although both groups considered the third factors important, the relative position and magnitude within this importance hierarchy is completely reversed. Industry experts, who are process oriented, point to design-related and manufacturing process problems; while DoD experts, who are more management and operationally oriented, point to top management and operational environment problems as the primary factors causing the reliability difference. DoD experts consider design-related and manufacturing process problems to have less impact on the reliability difference than do experts from industry. Meanwhile, industry experts rank top management commitment and understanding of the operational environment as both important contributors to the reliability delta.

6. Search for Root Causes of the Reliability Delta

What then does all this mean? This research has identified 11 factors which may affect the magnitude of the reliability delta. In a survey of reliability experts, the list was narrowed to six primary contributing factors. While the exact contribution to the reliability delta is unknown and unknowable, each of these six factors is thought to play a major role in the process and will be examined individually.

6.1 Definition Problems

Several authors have identified the problem with definitional problems and there are those who would downplay the significance of the reliability delta due to attributing all differences to definitional problems. It is interesting to observe that although both groups considered the third factors important, the relative position and magnitude within this importance hierarchy is completely reversed. Industry experts, who are process oriented, point to design-related and manufacturing process problems; while DoD experts, who are more management and operationally oriented, point to top management and operational environment problems as the primary factors causing the reliability difference. DoD experts consider design-related and manufacturing process problems to have less impact on the reliability difference than do experts from industry. Meanwhile, industry experts rank top management commitment and understanding of the operational environment as both important contributors to the reliability delta.

6.2 Representativeness of the Test Environment

It is impossible to replicate in a laboratory the dynamic environment encountered by missiles and planes. Imagine what designers and manufacturers have to deal with: virtually 100 percent availability for years on end and still have near perfect reliability in reaching and arming over the target. In a matter of less than five minutes the on-board equipment must undergo powerful g-forces and vibrations, rapid and dramatic temperature and pressure differentials, and then release the reentry vehicle in a position where it glows red hot from the friction as it reenters the atmosphere at several miles a second. Simulate that in a laboratory! Aircraft operate in similarly complex environments.

6.3 Specification of the Operational Environment

A major-and as of yet uncontrollable-factor in the specification of the operational environment may be due in part to the multi-year process currently required to bring systems on board. Even with an extremely short lead time, the dynamic nature of the environment will make any estimate dependent upon many assumptions which may not be valid when the system is deployed. A second un researched contributing factor may be related to the
experience level of individuals tasked with producing the statements of work.

6.4 Inaccurate Field Data

There are many contributing causes of inaccurate field data. First, when a malfunction occurs, it is the exception that can be clearly identified as a failure. It is even more rare to be able to identify a primary cause of failure. For data to be accurate, the collection systems require the maintenance technicians to have classification skills which require nothing short of divine intervention.-100 percent accuracy of failure classifications is an impossibility. Interestingly enough, automating the process does little to diminish the impact of the technician's lack of ability to distinguish among the various types of failures. Thus lack of the ability of anyone to isolate and identify root problems is and will continue to be a root cause of reliability problems.

6.5 Short-term Management Focus

The problem of people at all levels having a short-term focus will continue to hamper efforts to reduce the magnitude of the reliability delta. The tendency to treat cost and schedule as "food" and reliability as "vitamins" will always lower the priorities of reliability improvement program. Lack of continued focus on reliability will insure that reliability problems will persist.

6.6 Manufacturing Processes

Manufacturing processes provide the bridge between the prototype and the fielded weapon system and, as a result, contribute directly to the reliability delta. To say manufacturing process contribute to the reliability delta is one thing, isolating the specific contribution is much more difficult in that processes are a function of design. It may be theoretically possible to design the "perfect" system, that is unmanufacturable given current technology.

7. Logistics Impact of Reliability Delta

The logistician will typically relegate discussions of the reliability delta to the engineering world and consider arguments concerning whether an item was a "real" failure or not to be moot. The individuals tasked with keeping weapon systems operational see only field reliability--the plane will not fly, the radar will not work. There is no failure more real than the hole in the plane that he is tasked with filling. Quality is by necessity defined as "fitness for use." The fact that the environment and the technologies may have changed dramatically since the original specifications were released for bid is little consolation. The logistician has to make the system work despite these problems.

The accuracy of initial reliability estimates impacts the entire logistics infrastructure. Initial provisioning of spares is a function of estimated failure rates as well as the length of the repair pipeline. Maintenance running is based on projected workload. Thus, the effect of overstating reliability ripples throughout the logistics system. Higher than expected failure rates, in addition to increasing maintenance workload, may tax initial spares stores for newly-fielded systems.

However, to keep systems operational and work around the spares shortage, the "get-the-job-done" mentality of the operational commanders encourages potentially reliability-reducing activities such as cannibalism and in-house repair. Cannibalism—the practice of removing functioning parts from temporarily disabled weapon systems—can result in damage due to excessive handling or bad maintenance practices. As a minimum, the workload for the maintenance technician is increased dramatically. Meanwhile, in-house attempts at repair are aimed at avoiding having systems down for extended periods while waiting for the repair system to function. This unauthorized maintenance may be counterproductive in that it invalidates warranties for some items.

Additionally, with inadequate documentation, both cannibalism and in-house repair have the potential of masking the true failure rates. Although there may be many field failures, the item manager's visibility of the problem is impaired due to deficiencies in the reporting system.

Higher than expected failure rates also impact the repair pipeline. Additional supply and transportation transactions are required to process parts. For items in short supply, premium transportation rates are required to rush the parts back to the users.

The discussion of the real causes of the reliability delta will continue. The DOD reliability analysts, being at the receiving end of the development and acquisition process will continue to see management, environment, and data as being more important contributors to the reliability delta than design and manufacturing considerations. In contrast, the contractors accept as a given the accuracy of the contractual requirements and will make a quality product—where quality is defined as conformance to specification. Contractors will continue to see the front-end issues, design, data, and manufacturing as being the key factors which contribute to the inaccuracy of initial reliability estimates. It is not their fault if the specifications fail to describe the operational environment.

From the logistician's perspective, there is little utility in assigning blame for the causes of the reliability delta. Initial reliability estimates are invariably higher than demonstrated or field reliability. When "selling" Congress on a system, it may seem to be politically smart to use the optimistic reliability estimates for calculating a system's life cycle costs. However, such a strategy has caused the DOD's cost estimates to be greatly understated for many systems. The practice of ignoring the logistics impact of the reliability delta can gravely undermine the effectiveness of our military systems. Without explicit consideration of the impact, logistics support requirements will continue to be greater than anticipated.

Bibliography


Biography

Lt Colonel Phillip E. Miller, Ph.D. CPL
Air Force Institute of Technology
AFIT/LSM

Lt Colonel Phillip E. Miller is an Assistant Professor of Logistics Management and is currently the Department Head of the Logistics Management Department at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. He holds a Ph.D. in Business Administration from the University of North Carolina at Chapel Hill and specialized in Operations Management. Lt Col Miller is a member of the Society of Logistics Engineers (SOLE) and is a Certified Professional Logistician (CPL).

Lt Colonel Richard I. Moore, Ph.D. CPIM
Air Force Institute of Technology
AFIT/LSM

Lt Colonel Richard I. Moore is an Assistant Professor of Logistics Management at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. He holds a Ph.D. in Business Administration from the University of Georgia and specialized in Operations Management. Lt Col Moore is a member of the American Production and Inventory Control Society (APICS) and is Certified in Production and Inventory Management (CPIM).