

Reliability Growth of Mobile Gun System During Production Verification Test

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Product verification testing (PVT) plays an important role in the verification and demonstration of key performance parameters and system reliability of autonomous and manned systems. Considerable effort was put into improving reliability of the Stryker Mobile Gun System (MGS) before and during PVT. During PVT for the Stryker MGS, an unprecedented reliability growth rate of 0.38 was achieved. This article describes implementation of systems engineering principles employed during the MGS program, as well as system abort data analysis conducted using reliability growth analysis and the Design Actions Report and Tracking system. During reliability growth testing, it is very important to have a proper understanding of the test data that trigger proper engineering analysis and consequently fuel reliability growth of the system during its developmental testing. In order to substantially improve reliability of the system during product qualification testing or PVT, it is imperative to have well defined failure definition scoring criteria, established engineering root cause analysis processes, fast implementation of verified design fixes, and Design Actions Reports and Tracking that address observed failure modes. This article discusses the reliability methodology utilized during PVT of MGS as well as some of the systems engineering principles employed to actively improve the design of MGS. Such an approach completes the Test-Find-Fix-Test cycle, further improves MGS reliability, and meets the requirements for the mission equipment package. Substantial efforts were made not only to capture positive and negative outcomes of this program, but also to mature the MGS program into a design-for-reliability methodology that can be utilized in future programs with even greater success.

Key words: Product verification test; reliability; reliability growth analysis; Test-Find-Fix-Test cycle.

A recent report from the Defense Science Board Reliability Task Force suggests that almost 80 percent of military programs fail a reliability test the first time. Such findings indicate that reliability is usually not adequately addressed during the design process, and the program requires substantial redesign efforts before the product can be fielded. In December 2007, the Army Acquisition Executive, The Honorable Claude Bolton, published a memo¹ in which he proposed the implementation of the reliability test threshold values and reliability best

practices that would help a program focus on reliability during all stages of development. The Honorable John Young, Under Secretary of Defense for Acquisition, Technology, and Logistics, has directed that

“...effective immediately, it is Department policy for programs to be formulated to execute a viable RAM strategy that includes a reliability growth program as an integral part of design and development. Additionally, RAM shall be integrated within the Systems Engineering process....”²

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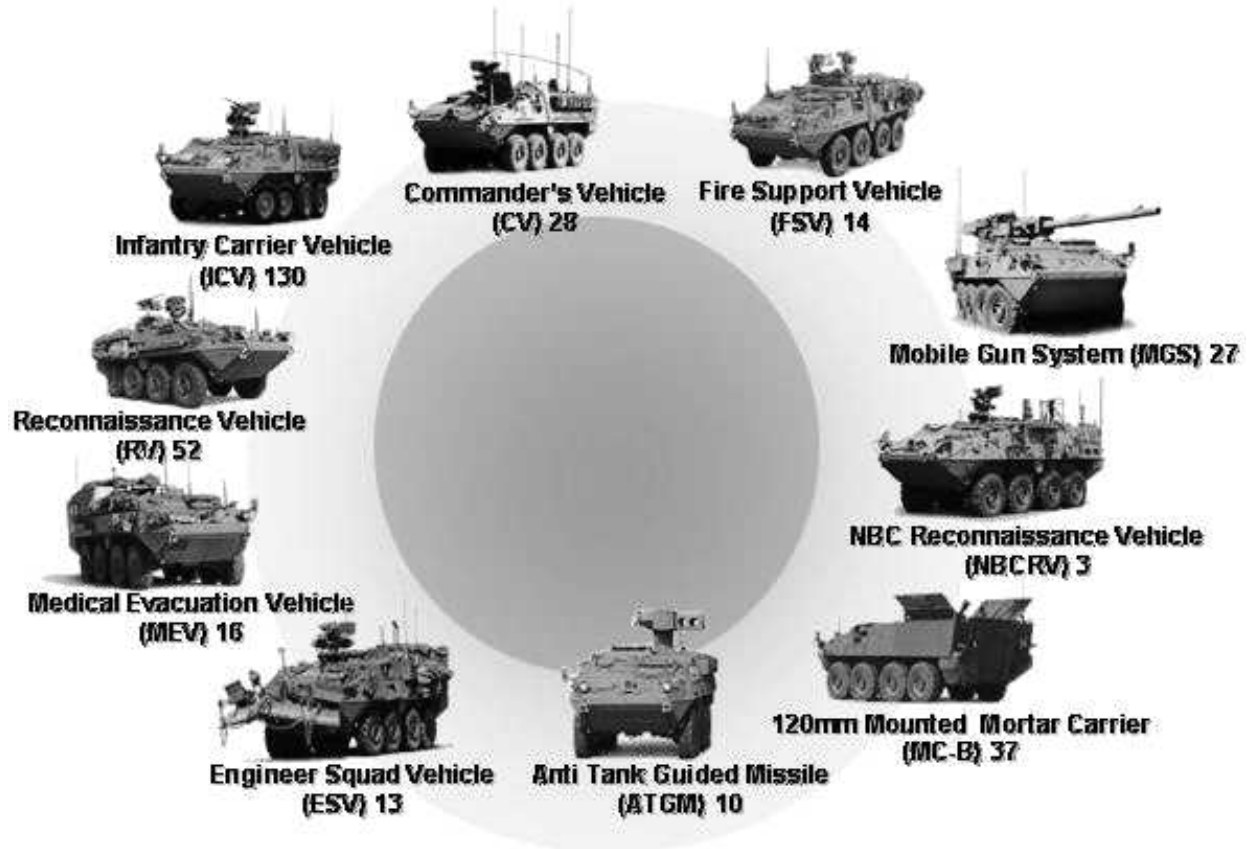


Figure 1. Stryker family of vehicles.

Major change in the U.S. Department of Defense reliability policy dictated by insufficient attention to reliability during product development will trigger some changes in program management as well as in the systems engineering organizations. That is why it is extremely important to capture positive lessons from successful programs such as the Stryker Mobile Gun System (MGS).

In this article, the authors discuss three major factors that ensured the MGS program met its reliability requirements during product verification testing (PVT):

- Program Management–Integrated Team,
- Systems Engineering–Reliability Attainment,
- Reliability Growth Analysis.

The main intent of this article is to illustrate practical applications of these factors and some near-term payoff programs should receive in terms of performance and reliability.

Stryker MGS

The Stryker family of vehicles is an eight-wheeled military combat vehicle being used by the Stryker Brigade Combat Teams and assembled into 10

different variants with a common chassis (Figure 1). Eight main designs were developed by General Dynamics Land Systems (GDLS) as the prime contractor, successfully tested, and then fielded with the U.S. Army during 2003–2005.

The Stryker MGS is by far the most complex and heaviest design of all the variants within the Stryker family (Figure 2). It incorporates the common Stryker chassis and low profile turret with 105-mm gun that is equipped with an ammunition handling system and auto-loader. The Product Qualification Test (PQT) conducted in 2003 revealed a variety of reliability and performance issues within the MGS design, especially with the ammunition handling system and the mission equipment package.

Between 2003 and 2006, program management made unprecedented efforts to redesign the MGS mission equipment package with an emphasis on its ammunition handling system. GDLS took the challenge and dramatically revitalized its systems engineering organization. Such efforts set the stage for an increase in reliability during the redesign stage and then use of the proper Test-Find-Fix-Test procedure during PVT. The first reliability growth plan devel-



Figure 2. Mobile gun system.

oped by a group of internal and external reliability experts established a planned reliability growth curve that connected an engineering process with measured reliability. Interestingly, predicted reliability for PVT was very close to the actual demonstrated reliability in 2008.

Success factors of MGS PVT

There are two main stages of product development in any program design or redesign activities and reliability growth testing. In order to achieve reliability requirements during design and subsequent test stages, the engineering community must employ robust engineering principles during the design stage and then manage failure modes during the test stage with a wide scope of timely issued corrective actions. Thus, the systems engineering team ensures initial reliability growth and then continues to develop improvements during the test phase. The program management team provides detailed schedule, proper budget, and resource management that supports the engineering team. And finally, the interpretation of the data from the test using reliability data analysis will direct the engineering efforts and will provide a proper assessment of the existing and/or potential reliability of the system. Below we will discuss all three elements in greater detail.

Program management

An initial assessment of Stryker MGS reliability during PQT revealed the shortcomings of the existing reliability growth program. The program management team developed the following plan to address the reliability issues:

- Phase I—Additional reliability testing to evaluate effectiveness of the corrective actions developed from PQT,
- Phase II—Systems engineering process improvement,
- Phase III—Redesign of major subsystems and integration.

These phases took place between 2003 and 2006 and then the program went into PVT in 2006. The main emphasis during these steps was made on systems engineering revitalization that will be discussed in the next section of this article. A Systems Engineering Reliability Growth Plan was developed to include both redesign activities and planned reliability growth testing.

It is important to point out that during the design or redesign stage of the reliability growth program (*Figure 3*) the engineering team focused on an inherent reliability or hardware/software reliability. The main efforts of the design process target the ability of the system design to perform its function reliably and robustly over a useful lifetime. On the other hand, the next phase of the Reliability Growth Plan will uncover problems affecting the operational reliability, i.e., inherent and induced failures. The latter can be described as operator/user errors, maintenance errors, accidents, etc. We will discuss those categories of failures later in this article. The same systems engineering process described here can address both aspects of operational reliability during both phases.

The program management team, working together between the Program Management Office Stryker Brigade Combat Teams and GDLS, were able to plan, budget, and execute the Reliability Growth Plan

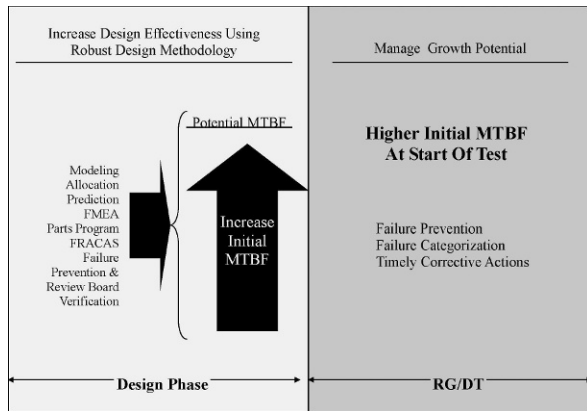


Figure 3. Reliability growth program.

successfully. Root cause analysis process followed by verification and validation of the corrective actions process became the major driving force behind the reliability growth of the MGS. Communication and explicit information about design deficiencies, verified fixes, and validation processes were key contributors to the overall success of the program.

Systems engineering (SE)

Engineering information about system performance during testing can be considered as feedback of the process that had designed such a system. It became obvious that current SE processes lacked focus on the reliability of the system. This conclusion triggered a systems engineering revitalization process that had system reliability as a main deliverable of the SE process. In addition to a very well defined SE master plan that served as guidance for the MGS redesign processes, the SE organization must have solid processes that govern every day activities, and SE management must have the associated metrics that adequately measure such processes. Thus, the SE organization focused on reliability processes, and appropriate management metrics formed the engineering core that was instrumental in achieving reliability requirements.

With the help of an external consultant, a revitalized SE process was developed and later used with great success on the MGS program. The process combines analysis and review of the system reliability requirements, system and subsystem design (redesign) for reliability, testing for reliability, and corrective actions tracking. A multifunctional and multilevel team of system and subsystem engineers formed a Failure Prevention and Review Board that became the driving force of the design improvement and was led by the Program Management Office. Such a process was developed and copyrighted by Dr. L. Crow and is presented in *Figure 4*.

The Design Actions Reporting and Tracking (DART) process discussed here manages the discovered failure modes as well as associated corrective actions through a redesign process driven by the Failure Prevention Review Board. Each DART created for an individual failure mode by an Incident Screening Team defines the seed of the database that can be used as a management measure of the process.

Thus, we have all elements of the successful process—the multifunctional engineering organization, a well defined process, and management metrics to adequately assess both the flow and aging of the process.

Also, it was found extremely useful to form affinity teams that address different common aspects of the design, such as a fasteners team, leak prevention team, integration team, etc. Because of the length limitations of this article, it is impossible to describe all the important steps, elements, and milestones of the GDLS SE process. However, a few extremely important elements must be noted.

The DART process generates a closed-loop failure mitigation system that not only drives the engineering correction process, but also helps to make statistical inferences from the test. Furthermore, the DART process or any other Failure Reporting and Corrective Action System connected to a Design Failure Mode and Effect Analysis or Failure Mode, Effect, and Criticality Analysis as a failure mode discovery mechanism can be the main driving force of the design for reliability approach. This methodology is being used by GDLS now on other programs.

It is imperative to note that major elements of the SE process initiated on the MGS program are described in the new “Reliability Program Standard for Systems Design, Development and Manufacturing.”³ It summarizes the four main objectives of the new standard:

- understand the requirements,
- design for reliability,
- produce reliable system,
- field and maintain the product.

The first three objectives correlate to the described above DART process.

Reliability data analysis

The last factor of a successful program is reliability data analysis. Indeed, the final reliability test is ultimately feedback on the previously described processes. Without proper inferences derived from the test and adequate data analysis, it is impossible to measure the reliability of the program. Limited sample size and test time can bias the outcome of the data

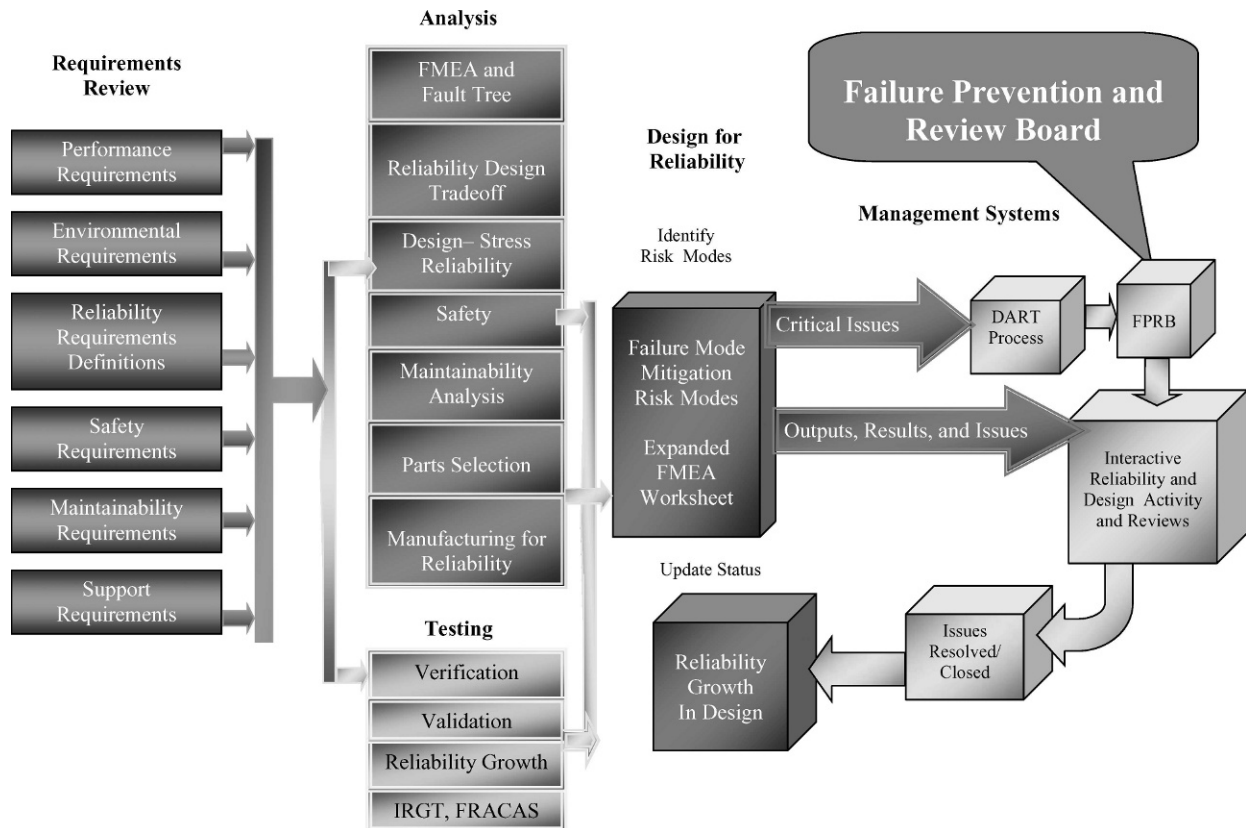


Figure 4. The design actions reporting and tracking process.

analysis and hinder the assessment of system reliability. But the reliability test is not only an evaluation tool but also a developmental tool, especially in the case of reliability growth. A developmental test or reliability growth test that is properly set up and planned can drastically improve the design of the system, even when it is conducted on a limited sample size.

MGS PVT was planned as a reliability growth test. The length of the test and planned idealized growth curve (Figure 5) suggested that the final measured reliability should be more than twice that of the initial measurement. The assumed reliability growth rate was 0.22, which is considered to be an average growth rate for Army developmental programs. It would be nearly impossible to perform reliability growth tests of a highly complex system such as the MGS without a highly efficient DART process and timely corrective actions incorporated on the test vehicles.

Reliability data analysis during the reliability growth test (i.e., reliability growth analysis) is described in details in MIL-HDBK-189⁴ as well as in DoD Instruction 3235.1 Chapter 9.⁵ MGS PVT reliability data analysis was described in depth in Chang and Rohall (2008). In this article we will emphasize a few important characteristics of the reliability growth analysis that helped to shape the assessment of MGS program, such as:

- failure definition scoring criteria,
- operational mission summary/mission profile,
- failure categories—inherent versus induced reliability,
- data grouping and modeling,
- instantaneous and cumulative mean rounds between system aborts.

Failure Definition and Scoring Criteria (FD/SC) and Operational Mode Summary and Mission Profile (OMS/MP) are the two most important contractual documents in the scope of work that govern the reliability performance of the system. The OMS/MP positively prescribes in what environment the system will be operated and what functions and in what sequence they should be performed. On the other hand, FD/SC discusses what is considered mission essential functions for the system, what constitutes as mission failure, measures of the severity level of such failures in regard to the mission success, and categorization of the chargeabilities of each failure. The matrix in the appendix to the FD/SC that addresses the potential failure modes as well as potential root causes is often translated from a System Design Failure Mode and an Effect Analysis and Fault Tree Model, the reliability tools that will help mitigate potential

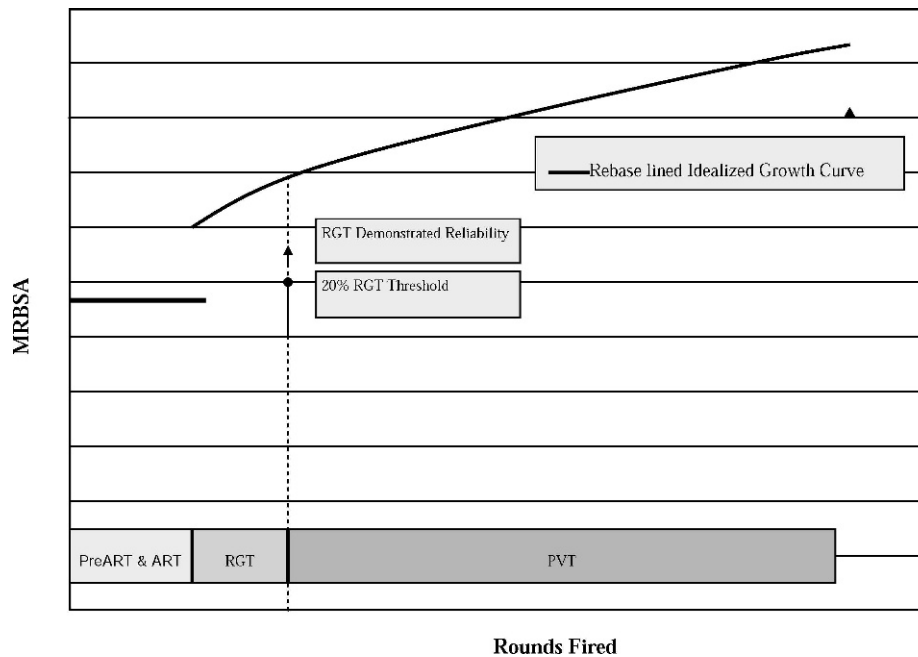


Figure 5. Mobile gun system idealized growth curve.

failure modes and attain reliability of the system earlier in the design stages. The matrix of FD/SC is a living document that needs to be updated as the configuration of the system changes due to engineering changes or redesign.

Properly executed tests per OMS/MP and a well written FD/SC will ensure a good reliability assessment during verification and developmental tests. Very often it requires performing a full root cause analysis on the failure incident before assessing its severity and thus properly employing FD/SC. It is extremely important that the reliability assessment and scoring process is completely decoupled from the prioritized list of design fixes.

Failure modes observed on the test have two distinct natures, i.e., inherent to the design (hardware failures) or induced by the operator and/or maintainer. From an inherent/induced perspective, one can distinguish hardware or design-related failures that characterize a system (hardware) capability to perform its intended functions. Such failures are usually called *hardware failures* and are associated with *inherent reliability*. That aspect of reliability is controlled by materiel developers and can be studied and addressed up front by employing the design-for-reliability discipline.

Inherent reliability or hardware failures can be further categorized as performance and reliability, signifying the difference in probability of repeat for each failure mode. For example, one can distinguish the performance failures as such failures when the system repeatedly fails under the given conditions of the test—wire melts at the

specific current, bracket breaks at the specific load, etc. Alternatively, reliability failure is the failure that has a probability of occurrence of less than 100 percent. Such failures are usually associated with wear or aging. A particular reliability failure mode can be described by statistical distribution function with the specific independent life variable (hours, miles, rounds, cycles, etc.) The latter category of failures is historically the most used inherent reliability.

Induced failures, on the other hand, are associated with use, operating, or maintaining the system and usually are induced by the user. It is feasible to minimize the risk (probability) of such failure by making the design “bullet-proof” or less prone to such abuse, but it is usually associated with cost. Also, it is much harder to address such an event up front in the design process, and it is much less controlled by materiel developers. All such categories (user/operator/maintainer) can be generalized as induced failures.

Inherent and induced failures together form the operational reliability. The danger and caveat are in using operational reliability for the assessment of program reliability when materiel developers can control only inherent or hardware reliability during the design stage. Obviously, all failures including induced and inherent failures must be addressed during the reliability growth test or the developmental test. The preferred way to address both inherent and induced failures is with a design change that completely eliminates the failure mode. Hence, the program should have explicit requirements for hard-

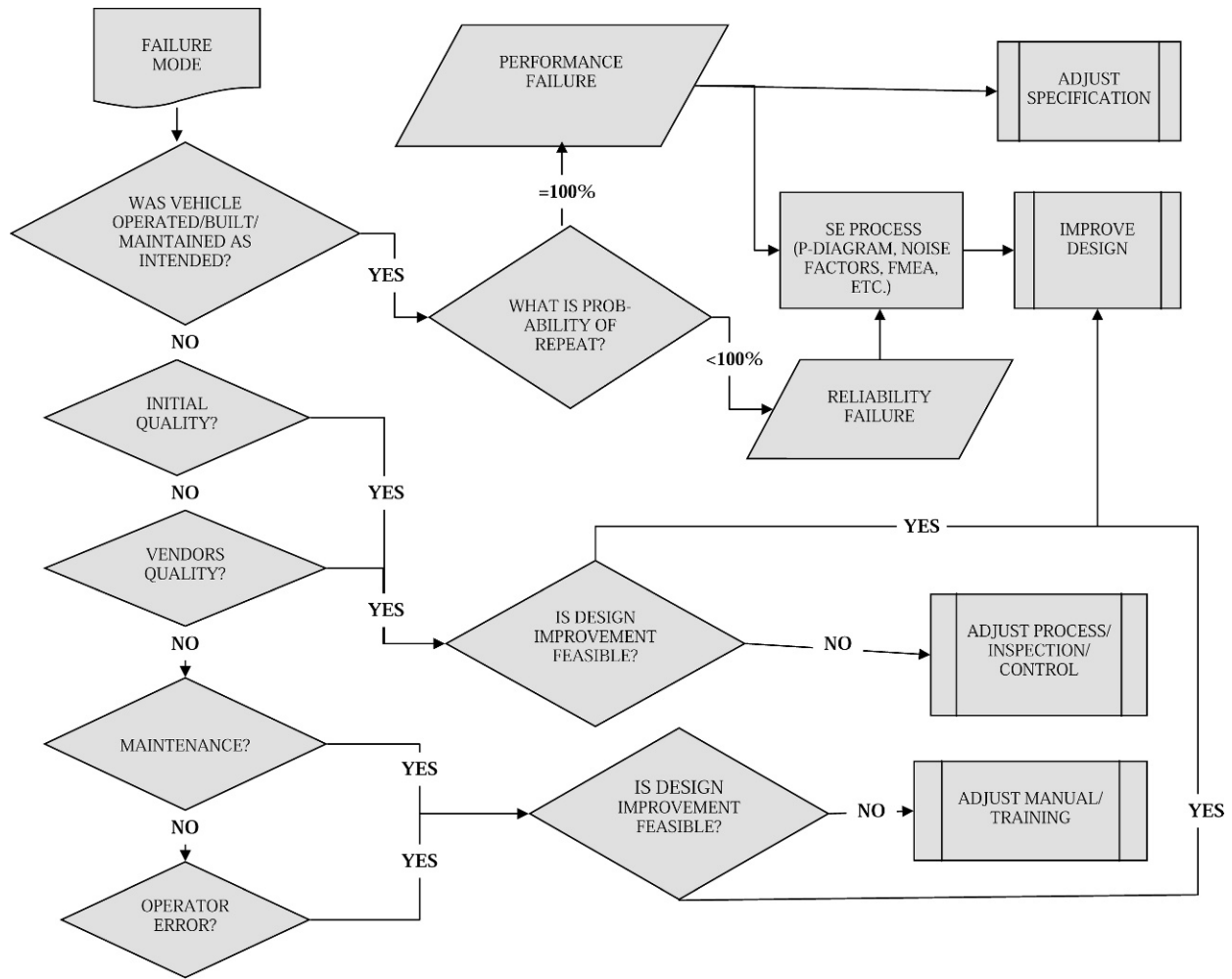


Figure 6. Failure categories.

ware or inherent reliability that indicate hardware capability to perform the mission and requirements for induced reliability as separate requirements.

In order to distinguish inherent and induced failures during the test, one can utilize the logic tree shown in *Figure 6*. The follow-up corrective action process can be derived from the failure category. It is understandable that induced failures do not depend on any independent life variables, such as miles, hours, etc., and cannot be modeled using statistical distribution functions.

Another important aspect of the reliability growth analysis, on top of sorting inherent and induced failures, is the proper way to prepare the data for reliability growth analysis modeling. It can become an issue when we consider complex systems on the complex test profile. MGS can be an excellent example of such systems.

As described in Chang and Rohall (2008), the MGS performs two major functions during OMS/MP—

accumulate miles and firing rounds. The test profile prescribes 86 rounds to be fired for each 1,000 miles traveled. MGS PVT was conducted on three different vehicles in two different locations. The scheduled maintenance for different vehicles happened at different times. So the rates at which all vehicles were accumulating miles and rounds were different and varied by the vehicle, location, and time.

It seems to be feasible to use a grouped data approach because of the complexity of the test profile. There are two ways the data can be reduced—one is using known equivalent time (based on daily accumulation of rounds and miles) and then group it by the points that closely resemble the test profile of 86 rounds per 1,000 miles; another is using unknown equivalent time, forming individual groups of accumulated 86 rounds and 1,000 miles per vehicle and then combining them into an overall system. Both approaches have been tested and produced very close results as the test matured.

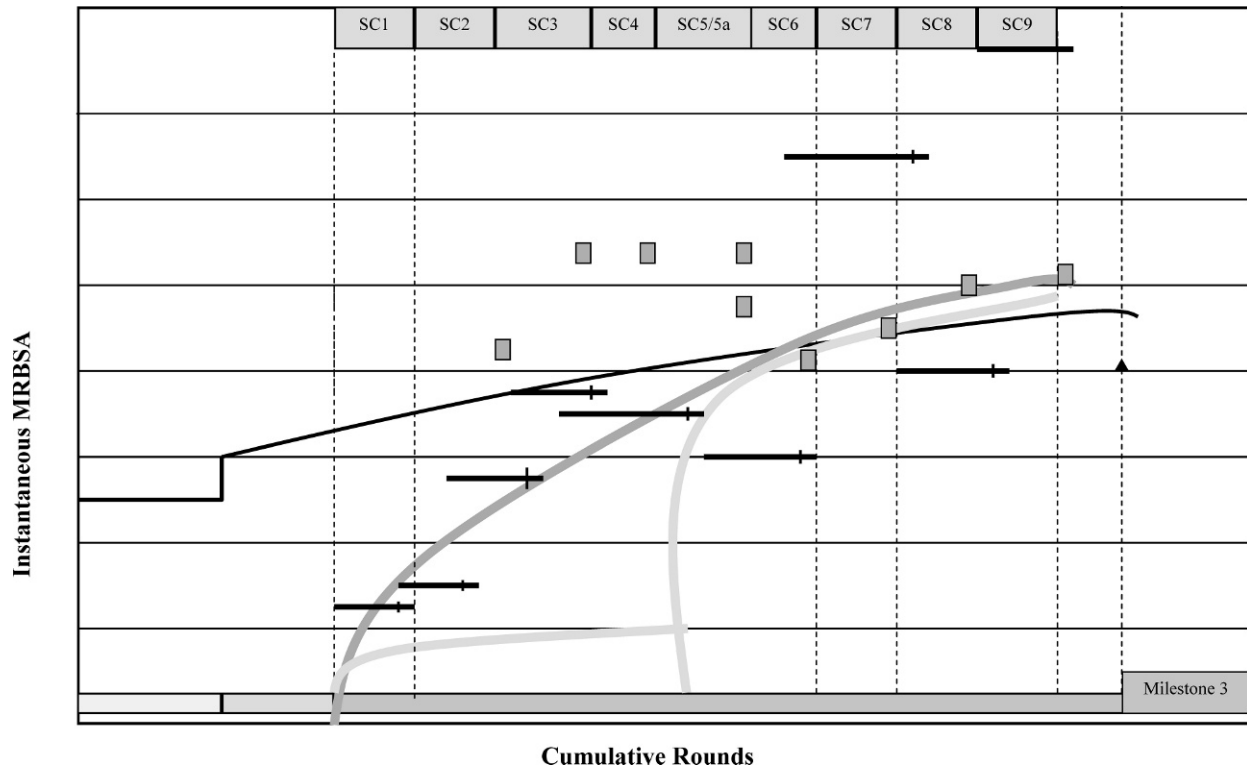


Figure 7. Planned and demonstrated reliability growth of mobile gun system during product verification testing.

The differences between such grouping techniques were obvious at the early stages of the test. Moreover, as the test progressed, the known equivalent time model became less stable and was more dependent on choosing pivotal points. Contrarily, the other model kept producing similar results throughout the conduct of the test. And, finally, it is natural to employ cumulative or average assessment of reliability during a verification or demonstration test when there is no major design alteration happening during the test. In such a scenario, the length of the test helps to build a confident estimate of the reliability of the system. One assumes no reliability growth sustained during the test.

In contrast to the above concept, any developmental or reliability growth test should employ the *instantaneous* concept for measuring and assessing reliability. Hence, reassessing the reliability as configuration of the system changes due to a corrective action implementation during the test must be properly measured using instantaneous values. Such factors can often be overlooked during initial stages of the reliability growth test when the impact of design changes is not as obvious as it becomes when the test matures.

Results and conclusions

The MGS PVT started in May 2006 and finished in April 2008. During the test, the MGS program

displayed steady reliability growth, with the growth rate approaching 0.38 (alpha value), which is an extremely high growth rate compared to historical data of similar systems. In the allotted amount of time (miles and rounds), the program exceeded its objectives and confidently met the reliability requirements, as shown in *Figure 7*. It was an undeniable success of the program that its reliability since PQT improved by almost 10 times.

The authors firmly believe that all three factors described here helped to drastically improve the reliability of the MGS, namely:

- Program management as an integrated team that was a driving force behind the reliability growth program.
- Revitalized systems engineering within the materiel developer organization that was instrumental in executing the design-for-reliability approach as well as timely corrective actions during the test.
- Accurate and adequate measure of the program health during the PVT using reliability growth analysis. Proper understanding and analysis of the observed failure modes that led to the right tracking of the reliability growth provides positive feedback to engineering and program management.

In Chang and Rohall (2008), PMO Stryker Brigade Combat Teams expressed their observation of the MGS PVT as follows:

“The successful MEP system reliability growth program of MGS PVT can be attributed to the following factors:

- The test program was planned to subject the system to test exposure and stress levels adequate to uncover inherent failure modes.
- The program office considered the requirements of the test schedule and resources required to support the ‘TAFT’ procedure.
- The materiel developer conducted an effective systems engineering process to identify and implement effective corrective actions.
- The reliability team applied reliability growth analysis techniques and developed a methodology to track and assess the reliability growth at every test phase.”

A positive lesson from MGS PVT will be applied to many different programs by GDLS and perhaps other defense contractors. It is important to address reliability from the beginning of the program. Without attention to reliability and driving efforts by the program management office, it is impossible to expect the program to meet its reliability requirements. Also, designing for reliability that blends into the systems engineering process will make the reliability program a viable path to meet the reliability requirements. Reliability program plan execution will require a schedule and budget commitment, but the initial investment into reliability will be significantly less than the capital spent later to fix the design. □

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Endnotes

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