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Reliability Methods for Improved Product Dependability White Paper



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26200 Lahser Road, Suite 200
Southfield, Michigan 48033
Phone: (248) 358-3570 • Fax: (248) 358-3253

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FOREWORD

Invitation

This White Paper has been developed to help gain feedback from parties interested in reliability methods. The AIAG Reliability Methods Work Group extends an invitation to all interested individuals to join and participate in further developing this white paper into a detailed guideline document. Please contact Co-Chairs Mark Braun at (219)-461-7611, Keith Radak at (313)-592-5227, any one of the Work Group members listed in Appendix G, or fill out the Maintenance Request at the back of this document with your suggestions and comments.

Mission Statement

The goal of the AIAG Reliability Methods Work Group is to provide a summary document of commonly suggested methods and guidelines for reliability analysis. This summary is based on a review of current industry practices performed by a team of reliability professionals assembled from the automotive / truck and heavy equipment industries.

Expected Benefits

Common practices will aid in communication, streamline the negotiation of reliability terms in contracts, and promote better cooperation among all the entities involved in producing a reliable final product.

Readers / Customers

Readers are expected to be technical and managerial personnel from companies involved in designing, manufacturing, marketing, and purchasing parts or systems in the automotive/truck and heavy equipment industries.

Background / Approach

The Truck and Heavy Equipment Reliability Work Group representatives and colleagues generated the following list of needs to addressed:

- Summary of Reliability Engineering ("Cradle to Grave")
- Common Reliability Guidelines / Practices
- Cost of Reliability Analysis Methods (Risk / Benefit Analysis)
- Reliability Reporting Methods (With focus on ease of showing and explaining)
- Reliability Tool Workbook

Technical Notice

The term "Reliability" has been applied knowingly within this document to various topics that technically lie in the domains of "maintainability" and "durability". Additionally, topics are included that are more commonly identified with "quality assurance", "quality control", and "quality improvement". These "technical errors" were committed to provide a more comprehensive document and to facilitate more widespread and easier use by persons not grounded in technical terminology and techniques. Summarily,

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the term "reliability" has been used according to its common usage and understanding within the truck and heavy equipment sector, in spite of, occasional technical impropriety.

ACKNOWLEDGEMENT

We want to thank the members of the AIAG Truck and Heavy Equipment Reliability Methods Work Group for their time and effort spent in writing, editing, and sharing ideas during the meetings and conference calls that were necessary for the completion of this document.

Dale Barker	Freightliner Corporation
Mark Braun	International Truck & Engine Corporation
Ronald Friend	Honeywell Sensing and Control Division
David Froning	SAS Institute, Inc.
Hank Gallmeyer	International Truck & Engine Corporation
Robert Grossnickle	Freightliner Corporation
William M. Harral	Arch Associates LLC
George Mouradian	Arch Associates LLC
Richard Pitel	Freightliner LLL – Alliance Division
Keith Radak	Detroit Diesel Corporation
Bob Rock	PAACAR
Steve K. Smith	Cummins, Inc.
M. A. Vasan	Results Systems Corporation
Michael L. Veillette	Arvin Meritor, Inc.
Mike Walmsley	Robert Bosch Corporation

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1.0 INTRODUCTION

1.1 Overview

The following chapters go into detail on the use of specific reliability tools in the various steps of product development from concept to launch and beyond. Because activities vary depending on the program phase, this White Paper is organized by phase. During the concept phase, testing evaluates the reliability potential of a product. This examination assists in selecting a final concept, identifies any high technical risks, and provides cost-effectiveness and trade-off information. Reliability requirements are set in the engineering development phase. Activities may include data collection, failure analysis, corrective action, and establishing reliability goals. In the design verification and validation phase, control activities are managed to ensure that the stated reliability requirements are being met. Failure data are statistically analyzed and the emphasis is on overall system planning. The purpose of testing during the process verification and validation phase is to evaluate reliability prior to the post launch monitoring/improvement phase.

1.2 Reliability Resources

There are many resources available for specifying reliability. Listed below are several that can and have been successfully used to support a reliability program.

- Internal sources of policy and documentation:
 - Corporate policy for reliability
 - Corporate organization for reliability
 - Reliability data collection systems
 - Product reliability design goals
 - Reliability prediction and allocation
 - Reliability procedures for design and performance validation
 - Reliability test procedures
- External sources of helpful planning aids:
 - QS-9000 – Advanced Product Quality Planning (APQP)
 - Reliability Programs for Systems and Equipment – MIL-STD-785
 - Reliability Tool Kit – Recommended Practices—USAF Rome Laboratory
 - Customer's Product Reliability Requirements
 - Competitor's Reliability Performance Assessment
 - Detailed Reliability Program Development Flowchart
- For further study refer to Web sites listed in Appendix C.

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Table 1 below is a reference enabling you to quickly locate the reliability techniques in this document. Also shown in the table are phases where a technique typically has primary or secondary usage. It is important to keep in mind, however, that each tool may also have appropriate application at other times during a product's life. (See Index for additional reference information).

Table 1. Reliability Tool Matrix

LEGEND: (1 = Primary Usage, 2 = Secondary Usage)	Concept	Engineering Development	Design Verification & Validation	Process Verification & Validation	Post-Launch Monitoring/Improvement	Defined in Chapter/ Page
Reliability Metrics (MTBF, MTTF, availability, reparability, cost per unit, B-life theory, PPM, R100, hazard rate, Signal/Noise ratios)	1	1	1	1	1	Appx A
Risk Analysis / Management	1	1	1	1	1	Ch 2 P 10
Design for Six Sigma (DFSS)	1	1	1	1	2	Ch 2 P 11
Quality Function Deployment (QFD)	1	1	1	1		Ch 2 P 10
Benchmarking	1	1	2		1	Ch 2 P 10
Reliability Allocation Model	1	1				Ch 2 P 13
Failure, Reporting, Analysis, and Corrective Action System (FRACAS)	2	1	1	1	1	Ch 3 P 14
Reliability Growth Modeling (e.g., Crow-AMSAA)	2	1	1	1	1	Ch 3 P 17
Weibull / Life Data Analysis (Mileage Profile by Vocation ref: <i>ActionLINE</i>)	2	1	1	2	1	Ch 3 P 17
Design Reviews	2	1	1	2		Ch 3 P 16
Design Failure Modes and Effects Analysis (DFMEA)	2	1	1		2	Ch 3 P 17
Fault Tree Analysis (FTA)	2	1	2	2	1	Ch 3 P 15
Reliability Block Diagrams	2	1				Ch 3 P 14
Degradation Analysis	2	1	1	1	1	Ch 3 P 15
Design of Experiments (DOE)		1	1	1	1	Ch 4 P 19
AIAG 7-Step Problem-Solving Tool		1	1	1	1	Ch 6 P 27
Design For Manufacturing and Assembly (DFMA)		1	1	1	2	Ch 3 P 17
Accelerated Testing		1	1	2	1	Ch 4 P 18
Design Verification Plan and Report (DVP&R)		1	1			Ch 4 P 18
De-rating Analysis		1	2			Ch 3 P 16
Highly Accelerated Life Test (HALT)		1			2	Ch 3 P 16
Highly Accelerated Stress Test (HAST)		1			2	Ch 3 P 16
Shainin® Techniques		2	1	1	2	Ch 4 P 19
Statistical Inference			1	1	1	Appx A
Early Warning Problem Identification			2	1	1	Ch 6 P 25
Production Verification Plan and Report (PVP&R)			2	1		Ch 5 P 21
Environmental Stress Screening			2	2	1	Ch 6 P 25
Process Failure Modes and Effects Analysis (PMFEA)				1	2	Ch 5 P 21
Six Sigma Problem Solving Methods				2	1	Ch 6 P 27

2.0 CONCEPT

2.1 Reliability Planning

The goal of reliability planning is to be proactive by anticipating and verifying probable failure modes and their causes in the design planning phase where it is most cost effective to address and resolve these issues, rather than fire-fighting to solve problems only after they have surfaced.

2.2 Reliability Program Development

A reliability program must be managed from the standpoint that corporate management, design engineering, and any potential suppliers agree to the reliability goals before beginning a new product design. This chapter will introduce the fundamentals of a reliability program. The program is used as a baseline to allow designers or application engineers to determine the depth and breadth of a reliability program to will suit their needs. Each reliability program requires the program manager to make decisions weighing the impact of cost versus reliability. A comprehensive reliability program provides an understanding of the risks these trade-offs entail.

Quality Function Deployment (QFD)

QFD is a process that develops a visual presentation of how the interactions of the customer's system of values (the voice of the customer) are related to the design, development, and manufacturing processes of a product. The result is a systems engineering process that prioritizes and connects the product development process so that it ensures product quality from a customer's point of view. A by-product of this process generates an environment conducive to concurrent engineering, which reduces cycle time in product development.

Benchmarking

Benchmarking is a process of continually comparing and measuring your organization's processes against other organizations, worldwide, to gain information about practices, processes, and methods that will help your organization improve its performance. Benchmarking candidates may include companies in or outside of your industry.

Risk Analysis / Management

Risk analysis and management provides a baseline of critical project attributes and assesses the risk that those attributes will have on the project's successful outcome. The intent of the risk analysis is to determine if all of the project's planning, development, and management resources are adequate to meet the requirements of the project. This is a proactive approach that identifies critical design, manufacturing, personnel, and process elements to prevent misdirection of the project management effort. Risk analysis also provides an early warning that identifies deviations from the project plan. This allows the adverse consequences to be resolved to a point where such a deviation will not have an unacceptable impact on the successful accomplishment of project.

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Designing for Six Sigma (DFSS)

DFSS is a process that identifies, documents, and ensures that external and internal customer requirements are understood and built into the solution of a product or service. Designing for Six Sigma (DFSS) helps to define the attributes that the customer considers “critical to quality” (CTQ).

2.3 Reliability Goals

These goals are developed from the voice of the customer through QFDs, DFSS, and from past failure history. Reliability goals need to be established in the concept phase of the design process. These goals are then tracked from cradle to grave to determine if a product development program is on target.

A Product Development Process should include some of the metrics listed in Table 2 below as Reliability Goals for the Program:

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Table 2. Reliability Goals

Reliability Metric	Description
Prior To Delivery (PTD) Warranty Allocation Model Opportunities	Six-Month warranty at dealership prior to customer taking ownership of vehicle; reflects assembly quality, process issues, and customer expectations versus product delivered.
12-Month Warranty Allocation Model Opportunities	Tracks 12-Month mature warranty per R100 and CPU to reduce the internal warranty cost, increase product uptime, and increase customer satisfaction.
Reparability Allocation Model Opportunities	Tracks the time to perform the typical repairs over the life of the product to increase ease of service, to increase uptime.
Prep & Delivery (P&D) Time Allocation Model	Reduces the time required to P&D the vehicle to the customer to reduce internal cost and to increase the speed of delivery to the customer.
Field Test Goals and Requirements	Ensures the vehicles are located in proper environments and applications. Identifies customer issues and increases market acceptance. Evaluates MTBF to ensure meeting customer expectations.
Durability Vehicle and Component Level Goals	States reliability, confidence, expected life, and component exceptions that identify modules that do not meet durability targets. Refer to AIAG's <i>ActionLINE</i> article in Appendix D – "Heavy Truck Mileage Profiles for Warranty and Reliability Analysis".
Maintenance Cost & Hours Allocation Model Opportunities	Tracks cost and hours over a specified mileage of operation, based on recommended maintenance intervals detailed in the Owner / Operator Manual, the time to perform each maintenance item, and dealer labor and part cost to complete that maintenance item.
Outstanding Life Cycle Value Goals	Sets goals that identify opportunities to decrease the customer's cost of ownership and operation beyond the warranty period of the vehicle.
Customer Satisfaction Goals	Tracks customer feedback in the field after launch. Identifies likes and dislikes of customers to drive continuous improvement.
Reliability Expense Goals	Identifies and reports the resources and expenses plan for the life of the product.

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Reliability Allocation Model

Each reliability goal in Table 2 should have a Reliability Allocation Model to track progress through the life cycle of the product. Following is an example of vehicle level 12-Month warranty R100 and CPU elements:

Table 3. Reliability Allocation Model Elements Example

Elements	Description	Metric	Chassis	Body	Electrical	Total
Base / Actual	This is where you are with the current product at the start of the program.	R100	254	186	130	570
		CPU	\$456	\$345	\$235	\$1036
		Life CPU	\$550	\$356	\$246	\$1606
Potential Target or Commitment	This is your end-goal that has been negotiated among the functions, program team, and business.	R100	127	93	65	285
		CPU	\$228	\$173	\$118	\$519
		Life CPU	\$275	\$178	\$123	\$804
Forecast	This is where you expect to end up at maturity, usually at product launch. Where you expect to end up is not necessarily the same as your target.	R100	198	104	63	365
		CPU	\$385	\$198	\$102	\$685
		Life CPU	\$438	\$216	\$115	\$769
Better / Worse (B / W)	Simple calculation: Forecast minus Target or Target minus Forecast, based on which is better or worse. This will change depending on the specific metric.	R100	(71)	(11)	2	(80)
		CPU	(\$157)	(\$25)	\$16	(\$166)
		Life CPU	(\$163)	(\$38)	\$8	(\$193)
Design / Process Validated	Final assessment at product launch	R100				
		CPU				
		Life CPU				
Continuous Monitoring	Monitor product in the field to determine if targets are achieved; review Lessons Learned	R100				
		CPU				
		Life CPU				

3.0 ENGINEERING DEVELOPMENT

After reliability goals are defined, the most potent and cost-effective use of reliability engineering occurs during design development. Problems, identified early, can usually be corrected before large quantities are produced. The threat of high costs down the road due to product unreliability is the driving force for making improvements up front. The higher profits and increased customer satisfaction come only if upper management recognizes the benefit of investing in reliability engineering and allocates resources appropriately.

Reliability engineering addresses the broad issue of quality conformance during the intended product life cycle. The key issue is the added dimension of time while products are exposed to the possibility of failure. This contrasts with the static issue of standard quality conformance—such as dimension or material property measurement—which is often independent of expected usage duration. The complete analysis requires realistic environments and loading that simulates actual usage.

Tools available to the reliability engineer for design development analysis include FRACAS, Reliability Block Diagrams, Degradation Analysis, Fault Tree Analysis, Risk Criticality Analysis, Design Reviews, De-rating, HALT / HAST, Design FMEA / System Integration Methodology, Reliability Growth Modeling, and Weibull / Life Data Analysis.

3.1 Failure Reporting, Analysis, and Corrective Action Systems (FRACAS)

FRACAS is a closed-loop system of initiating reports, analyzing failures, and feeding back corrective action into the design, manufacturing, and test processes to promote reliability improvement throughout the life cycle of a product.

3.2 Reliability Block Diagrams

Reliability Block Diagrams indicates the functional reliability relationship between components in an assembly and between assemblies in a system. The two most common representations are the series relationship and the parallel relationship. Complex reliability arrangements can be modeled by combining serial and parallel combinations.

A series reliability combination between parts represents the situation where all of the components need to function correctly in order for the next assembly to function correctly. This is analogous to analyzing the open-circuit failure mechanism in resistors that are connected end-to-end in a circuit. If any single resistor fails, then the entire group of connected resistors cannot function properly. A series relationship is depicted in the reliability block diagram as blocks connected end-to-end. If $R(A)$ represents the reliability of component A and $R(B)$ represents the reliability of component B, then:

$$\text{Series Reliability Of A And B Elements} = R(A) * R(B)$$

A parallel reliability combination between parts represents the situation where just one of the parts need to function correctly in order for the next assembly to function correctly. A dual-throttle return spring system is a good example. A single spring failure will not lead to loss of throttle control. A parallel relationship is depicted in the reliability block diagram as blocks sharing the same input and the same output.

$$\text{Parallel Reliability Of A And B Elements} = 1 - [(1 - R(A)) * (1 - R(B))]$$

The reliability block diagram can be used to quantify the overall system reliability based on reliability values for the individual components. Additional relationships besides series and parallel are possible and can be modeled mathematically for any relationship.

3.3 Degradation Analysis

Degradation Analysis provides an ongoing estimate of a component's long-term failure modes that cannot be easily duplicated in testing, such as seal hardening in storage, springs taking a "set," deformation of a non-metal under load. These effects take a long time to become apparent and can usually be addressed by reviewing historical reliability and warranty records of similar products or components.

3.4 Fault Tree Analysis

Catastrophic or significant events may require Fault Tree Analysis, which starts with the significant event (at the top) and identifies associated intermediate causes (middle) and finally the original root causes (at the bottom). Probabilities can be associated with each underlying event in the tree structure and combined probabilistically to provide a way to calculate the probability of the top event occurring.

A fault tree is a subset of the events depicted in the corresponding FMEA analysis. Only those events that lead to the significant event are included in the fault tree.

3.5 Risk Criticality Analysis

Assigning criticality categories and associated failure probability to each failure possibility provides a complete risk analysis. This is often combined with an FMEA analysis. A typical set of criticality categories might be:

- Category 4: Catastrophic - such as human death or loss of a safety related or a large complex system
- Category 3: Significant - such as OSHA reportable level human injury or major loss of part of a non-safety related system
- Category 2: Minor - such as loss of a non-safety related system function for some time
- Category 1: Negligible - such as nuisance, or spurious activation of indicator lights or horns

3.6 Design Reviews

Preliminary Design Review (PDR) and Critical Design Review (CDR) coordinate the design effort and re-focus priorities.

The PDR should be held after the conceptual design is complete. Component sizing, de-rating, and duty-cycle are reviewed along with overall assembly reliability and complexity. At this stage suggestions should be made to improve the concept.

The CDR should be held after the detail design is complete and before any hardware is manufactured for development testing and production. Precise reliability assessments should be performed including assessment of all detail parts. Manufacturing and maintainability issues should be addressed.

3.7 De-rating Analysis

De-rating results in providing sufficient safety factor between part loading and actual part capability. De-rating of components is common for electric/electronic parts. Here the temperature capability considered for the part may be lowered although the actual temperature capability remains high. Components de-rated in this manner are expected to work better and last longer.

3.8 Highly Accelerated Life Test (HALT)

A reproduction of the actual environment the product will be used in. HALT provides a test tailored to the product's intended life environment and produces data on where in the life of the product a relevant failure occurs. HALT results can be effectively analyzed with statistical methods, such as Weibull / Lognormal distribution analysis, along with knowledge of the acceleration factor, to form a basis for prediction of field performance. The acceleration factor is the ratio of the actual service environment lifetime to test lifetime. $\{A = \text{acceleration factor} = (\text{actual service environment lifetime})/(\text{test lifetime})\}$ The disadvantage is that this type of testing typically requires much more time than HAST.

3.9 Highly Accelerated Stress Test (HAST)

Overstressing the product in an effort to induce fatigue, which causes failure and reveals weaknesses. HAST provides a quick means of identifying product weaknesses prior to design verification testing. The disadvantage is that the product weakness may never occur in the product's actual life.

3.10 Design for Manufacturing and Assembly (DFMA)/System Integration Methodology

System integration in production can produce failures not associated with any single component. Such possibilities must be considered in the preliminary design. Human errors such as mis-assembly can be mitigated with Design for Manufacturing and Assembly (DFMA) strategies.

3.11 Design Failure Mode and Effects Analysis

The Failure Modes and Effects Analysis (FMEA) method lists each detailed functional part to its lowest level and includes all higher assemblies. It is an audit of all of the failure possibilities and the consequences of those failures to the next higher assembly.

Reliability Growth Modeling

Crow / AMSAA (Duane), and other growth modeling techniques track changes in reliability over time.

3.12 Weibull / Life Data Analysis

Weibull can measure reliability for the following data types:

1. “Standard Data” – All failure and suspension times are known.
2. “Mixed or Competing Failure Modes” – Failure and suspension times are known but failure modes are not known.
3. “Interval, Grouped, Coarse or Non-Destructive Inspection Data” – The exact failure time is not known – only the interval in which the failure occurred is known.
4. “Quantal or Destructive Inspection Data” –Each observation is either censored or failed.

Please refer to Appendices E. (Rock, "Selecting the Best Practice for Your Life Data Analysis," SAE International 2000 Weibull Users' Conference, 2000.)