START

Selected Topics in Assurance Related Technologies

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Design for Maintainability (DFM)

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Introduction

The pressures of a global market continue to force companies to consider all aspects of product performance in an effort to remain competitive. An important aspect of product performance is maintainability. This START Sheet provides some insights into designing a product for maintainability.

Many durable products require maintenance throughout their useful life. Thoughtful consideration of a product's maintenance features early in the design process can reduce or eliminate maintenance costs, reduce downtime, and improve safety.

What is design for maintainability? First, design is the transformation of an idea into a product, process, or service that meets both the designer's requirements and end user's needs. Second, maintainability is the degree to which the design can be maintained or repaired easily economically and efficiently. We can now define design for maintainability as a design strategy, involving both the designer and end user, with the following objectives.

- Identify and prioritize maintenance requirements.
- Increase product availability and decrease maintenance time.
- Increase customer satisfaction.
- Decrease logistics burden and Life Cycle Costs.

The effectiveness of a design for maintainability strategy can be measured using maintenance metrics and industry benchmarks.

This START Sheet covers design for maintainability principles, benefits, and measurement.

Principles of Design for Maintainability

The notion that a product's maintainability should be given strong consideration in the initial product development stage is driven by the fact that maintenance and the associated costs are accrued over the entire life of the product. Because maintenance costs can be a significant factor in a product's overall cost, it is essential that maintenance be considered early in the design when flexibility is high and design change costs are low. As shown in Figure 1, design flexibility is greatest in the conceptual stage of the product and design change costs are low. As the product nears production, design flexibility decreases and design change costs rise. Some companies report that changes made in production cost 100 to 1000 times as much as those made in the early concept stage.

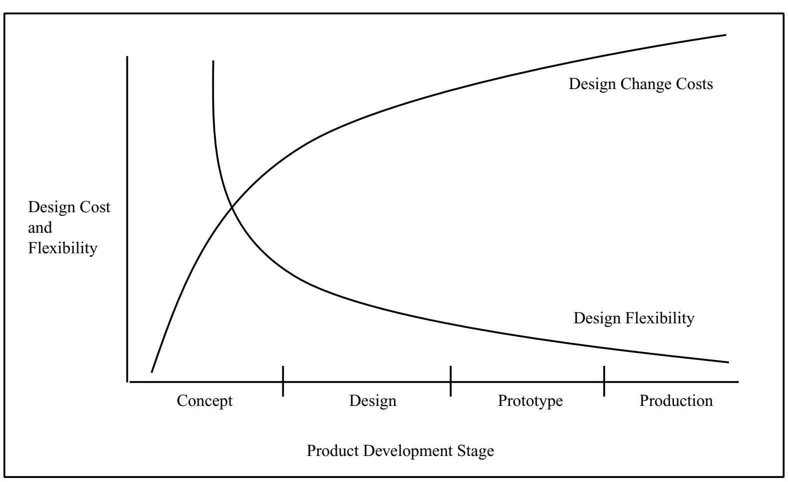

Figure 1. Product Phase vs. Product Costs/Flexibility

START 2001-4, DFM

Addressing maintainability during design reduces the end user's maintenance costs over the product's life. It may, however, increase the costs to manufacture. For example, it is cheaper and faster to spot weld panels together rather than use many fasteners. But welded panels would make it very difficult and expensive to make repairs in the field. By increasing product availability, a manufacturer can increase market share and enjoy a higher production run and higher profits over the life of the product. Customers get a product that is economical to operate and is available when needed.

Design for Maintainability (DFM) is a closed loop process using the following principles:

1. Use a team approach with DFM as a goal. A company's product development team should include individuals involved with design, manufacturing, product maintenance, and customer support.
2. Gather maintenance data and develop into information. Maintenance data can be gathered from the company's service people, field data collection system, customer surveys, and warranty information. The data is then developed into information that supports decisions.
3. Develop/identify maintenance concepts using information. Some customers will dictate the maintenance concept they will use. In other cases, the manufacturer must develop the maintenance concept. The product development team can generate product maintenance concepts based on the information from Step 2. The selected maintenance concept is an important design constraint.
4. Design product using selected maintenance concepts. The design process begins using a systems approach and a variety of design tools, design rules, and approaches. At this stage, flexibility is great and design change costs are low.
5. Design, analyze, test, and improve the product. Based on the results of analysis and test (a prototype of portions of the product or even the entire product may be built), the design evolves. Maintenance concepts are reviewed and possibly revised. Flexibility is decreasing and design change costs are rising.
6. Manufacture the product and release to market. Engineering finalizes the design and releases the product to manufacturing. At this point, flexibility to modify the product maintenance features is low and the change costs are high.
7. Collect field maintenance data and develop information. Collect product field data in the form of customer feedback, warranty information, surveys, and service work. The information derived from this data can be used to evaluate the performance of the product in the field (Step 8) and in designing new products (Step 9).
8. Make field improvements as required by safety, economics, and other factors. Initial field performance may be lower than anticipated and additional changes to the design, procedures, or maintenance concept must be considered. At this point, modifying the product is very difficult and expensive. Only those changes dictated by customer acceptance or safety, or that are economically attractive will be made.
9. DFM process repeats with next generation product. Based on information generated from the field data, the design for maintainability process is repeated for the next generation product. Design rules may be revised, new tools developed, and design approaches validated or revised.

Design for Maintainability Features and Benefits

The objective of the design for maintainability is to provide benefits (value) to both the manufacturer and the end user. As quality and price differences among products diminish, manufacturers must find other incentives to convince customers to purchase their products. One such incentive is a high level of maintainability.

Durable products have long life cycles and many require both scheduled and unscheduled maintenance throughout their lives. Companies with a disciplined DFM program can design maintainability into their products and use this attribute as a discriminator, making their product more attractive to customers.

Table 1 lists typical design for maintainability features used in the product development stage and the benefits these features provide to the designer and the customer. Note that Table 1 lists DFM features and benefits found in many electromechanical products. DFM can also be used for software, service operations, and processes.

While the DFM features and benefits in Table 1 might seem obvious, without the design for maintainability process, many of the features that make a product maintainable might not be realized during the product development stage.

Measuring the Benefits of Design for Maintainability

Table 2 lists several metrics that can be used in measuring design for maintainability benefits. This list is not inclusive and may vary depending on the product and/or industry. As Table 2 shows, maintenance metrics can be generated using a number of data sources.

Table 3 lists several industry maintenance cost benchmarks collected by the Plant Maintenance Resource Center (http://plant-maintenance.com/benchmarking.shtml). A company can compare its own maintenance metrics with benchmarks like these to determine the level of maintenance competency.

Table 1. Design for Maintainability Features/Benefits Matrix

Design for Maintainability Features	Design for Maintainability Benefits
Easy access to serviceable items	• Maintenance time and costs reduced • Product availability increases • Technician fatigue/injury reduced
No or minimal adjustment	• Maintenance time and costs reduced • Product availability increases • Maintenance training curve reduced
Components/modules quick and easy to replace	• Technician fatigue/injury reduced • Product availability increases • Problem identification improves
Mistake proofing, part/module installs one way only	• Probability of damage to the part or product reduced • Reliability improves • Maintenance training curve reduced
Self-diagnostics or built in test or indicators to find problems quickly	• Maintenance time and costs reduced • Product availability increases • Customer satisfaction improves
No or few special hand tools	• Maintenance investment reduced • Customer satisfaction improves • Tool crib inventory reduced
Standard fasteners and components	• No. of spare parts in inventory reduced • Product cost reduced • Maintenance time and costs reduced
Reduce number of components in final assembly	• Product cost reduced • Reliability improves • Spare parts inventory reduced

Table 2. Design for Maintainability Metrics

Maintenance Metrics		
Design Attributes	**Field Costs**	**Field Performance**
• Accessibility • Testability • Standardization • Human-factors • Times to Repair	• Repair Costs • Total Costs • Maintenance Payroll • Maintenance Mgt. Costs • Training Costs	• Maintenance Work Orders/Year • Downtime • Total Maintenance Hours • No. of Maintenance Personnel • Induced Failures

For Further Study

1. Engineering Maintainability: How to Design for Reliability and Easy Maintenance by Balbir S. Dhillon, April 1999.
2. MIL-HDBK-470A, Designing and Developing Maintainable Products and Systems, Department of Defense, 4 August 1997.
3. NASA, NASA TM 4628A, "Recommended Techniques for Effective Maintainability", http://www.hq.nasa.gov/office/codeq/mtecpage/mtechniq.htm.
4. Reliability Analysis Center's Reliability Toolkit: Commercial Practices Edition, see Maintainability sections.
5. Society of Manufacturing Engineer's TMEH Handbook, Volume 6, "Design for Manufacturability", Fourth Edition, pages 10-65 to 10-70.

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5. NASA, NASA TM 4628A, "Recommended Techniques for Effective Maintainability", http://www.hq.nasa.gov/office/codeq/mtecpage/mtechniq.htm.

About the Author

Andy FitzGerald is a research engineer with IIT Research Institute's Advanced Technology Group and Reliability Analysis Center (RAC). IITRI/RAC projects Mr. FitzGerald is or has been involved in include; several US Air Force Depot maintenance projects, reliability related commercial projects, and design of test systems and maintenance equipment.

Mr. FitzGerald has seven years experience in engineering services, four years experience in aerospace manufacturing, and six years experience in heavy equipment manufacturing. He holds an MS and BS degree in Industrial Technology from Colorado State University and is a Certified Manufacturing Technologist by the Society of Manufacturing Engineers.

Table 3. Industry Maintenance Benchmark Information

	Maintenance Costs % of Total Costs	Maintenance Costs % of Plant Replacement Value
	Oil and Gas Extraction	
Best	27.50%	2.91%
Worst	49.41%	21.76%
	Manufacturing: Metal Products	
Best	2.68%	0.83%
Worst	50.00%	11.76%
	Utilities: Electricity Generation	
Best	8.98%	1.34%
Worst	66.89%	12.50%
	Forestry and Logging	
Best	12.50%	100.00%
Worst	12.50%	250.00%
	Mining: Metal Ore	
Best	25.00%	6.99%
Worst	40.41%	20.00%
	Manufacturing: Food	
Best	2.50%	0.20%
Worst	46.15%	81.25%
	Manufacturing: Wood & Paper Products	
Best	0.98%	1.64%
Worst	33.82%	8.54%
	Chemical & Associated Products	
Best	0.00%	0.00%
Worst	53.26%	150.00%
	Manufacturing: Machinery & Equipment	
Best	2.00%	0.79%
Worst	2.00%	0.79%

Note: 1. "Maintenance Costs % of Total Costs" is the annual maintenance cost as a percentage of total annual plant costs.
2. "Maintenance Costs % of Plant Replacement Value" is the maintenance cost as a percentage of plant asset replacement value at a given time.

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http://plant-maintenance.com/benchmarking.shtml

Other START Sheets Available

Many Selected Topics in Assurance Related Technologies (START) sheets have been published on subjects of interest in reliability, maintainability, quality, and supportability. START sheets are available on-line in their entirety at http://rac.iitri.org/DATA/START.

For further information on RAC START Sheets contact the:

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About the Reliability Analysis Center

The Reliability Analysis Center is a Department of Defense Information Analysis Center (IAC). RAC serves as a government and industry focal point for efforts to improve the reliability, maintainability, supportability and quality of manufactured components and systems. To this end, RAC collects, analyzes, archives in computerized databases, and publishes data concerning the quality and reliability of equipments and systems, as well as the microcircuit, discrete semiconductor, and electromechanical and mechanical components that comprise them. RAC also evaluates and publishes information on engineering techniques and methods. Information is distributed through data compilations, application guides, data products and programs on computer media, public and private training courses, and consulting services. Located in Rome, NY, the Reliability Analysis Center is sponsored by the Defense Technical Information Center (DTIC). Since its inception in 1968, the RAC has been operated by IIT Research Institute (IITRI). Technical management of the RAC is provided by the U.S. Air Force's Research Laboratory Information Directorate (formerly Rome Laboratory).