

Managing Reliability in the 21st Century

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1. Introduction

The rapid pace of change at the end of the 20th Century should continue unabated well into the 21st Century. The driver will be the marketplace imperative of "faster, better, cheaper." This imperative has already stimulated a revolution-in-engineering in design and manufacturing. In contrast, to date, reliability engineering has not undergone a similar level of change.

It is critical that we implement a corresponding revolution-in-reliability-engineering as we enter the new millennium. If we are still using 20th Century reliability approaches in the 21st Century, then reliability issues will be the limiting factor in faster, better, and cheaper. At the heart of this reliability revolution will be a science-based approach to reliability engineering. Science-based reliability will enable building-in reliability, application-specific products, virtual qualification, and predictive maintenance.

The purpose of this paper is to stimulate a dialogue on the future of reliability engineering. We will try to gaze into the crystal ball and predict some key issues that will drive reliability programs in the new millennium.

2. Major Trends and the Impact on Reliability

Table I summarizes some major changes that are impacting the business of providing

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Trend	Impact on Reliability
Customers Want Increased Reliability & Warranties	<ul style="list-style-type: none"> Uncover and manage subtler failure modes Extrapolate farther out on distributions Harder to demonstrate reliability Increased warranty cost risk
Customers Don't Want to Make Sacrifices for Higher Reliability	<ul style="list-style-type: none"> Reliability must have the minimum impact on other desirable attributes Need to be able to quantify tradeoffs of reliability and risk vs. design/manufacturing variables
Agile Manufacturing (easily customizable products)	<ul style="list-style-type: none"> Application-specific reliability and qualification
Virtual Manufacturing (teams of independent companies)	<ul style="list-style-type: none"> Loss of total control for a product's reliability Must manage reliability across multiple, independent organizations
Rapid Technology Change	<ul style="list-style-type: none"> Bring technology to market with incomplete reliability knowledge (new failure modes, predictive models, ...)

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competitive products. Customers relentlessly want better reliability and warranties. But they want this improved reliability for free, that is, without sacrificing cost or performance. Customers also want products tailored to their exact needs, and so companies will have to become "agile" manufacturers. These manufacturers will more and more not be the old, permanent, vertically integrated companies but rather a virtual organization consisting of temporary teams of independent, geographic dispersed companies. Finally, there will be an increase in the rate and significance of the evolution of technology. A strong profit motive will rapidly drive these products to market, whether their reliability issues are resolved or not.

Table I also considers the impact of these trends on reliability. Higher levels of reliability will make it increasingly harder to competitively ensure reliability using testing and screening. Higher levels of reliability, along with new technologies, will also introduce new failure modes that will have to be identified, modeled and mitigated. All of these challenges will increase the risk of warranty cost exposure.

The needs of internal design, manufacturing and marketing groups will be as important to the reliability group as the needs of external customers. The value of reliability will not only be in making the *small subset of parts* that fail even smaller. It will also add value to *all products* by enabling designers to go right up to the performance edge without falling off a reliability cliff. Similarly, generic qualification of a technology or product family will allow the rapid development of a range of customized parts with the need for individual qualifications. Last, but not least, reliability improvements will be needed to reduce the time and risk of bringing radically new technologies and products to market.

3. Reliability Requirements

The requirements of the next century's reliability programs are shown schematically in Figure 1. The overarching goal is to add quantifiable value to the organization's business plan. To do this, the life cycle system of activities that constitute the reliability program will have to be

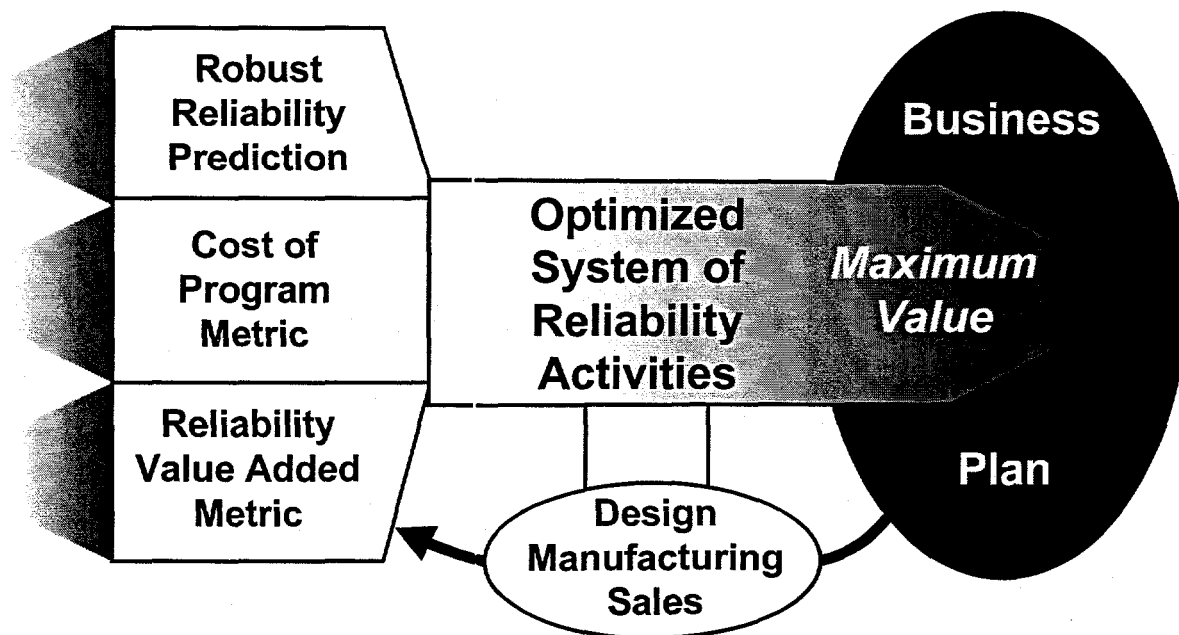


Figure 1. Required 21st Century reliability program elements.

optimized around this goal. This optimization requires three things.

First, there must be a very robust capability to predict reliability. The capability must be able to make quantitative predictions of reliability as a function of design, manufacturing and end-use variables. The reliability prediction also needs to provide a quantitative estimate of the risk (confidence) in the correctness of the predictions. Furthermore, it must be able to do this at the start of the product development cycle.

Second, there must be a metric that describes the cost of the reliability program as a function of how the life-cycle reliability system is designed (e.g., how many simulations or tests should be run).

Third, there must be a quantitative metric of how the reliability program adds value. The metric will be different from organization to organization due to differences in business plans. A common feature of these metrics will likely be the costs associated with a failure:

- The direct cost of a field failure (e.g., warranty costs, liability costs)
- The cost of the loss of future business due to customer reactions to failures
- The cost of the lost opportunity to enhance performance or other desirable attributes on every product due to the restrictions of overly conservative reliability margins
- The cost of being late to market due to reliability qualification delays

The life-cycle system of reliability activities will be (subject to organization-specific constraints) designed to minimize total costs (=cost of failure + cost of reliability program). Whatever the metric, it must be quantifiable and it must be available at the start of product development.

4. Science-based Reliability Engineering

Reliability is currently the weak link in faster, better and cheaper. Reliability programs have not seen the revolutionary quantum improvements that have occurred in design and manufacturing. Reliability must move from testing/screening to building-in reliability and virtual qualifications.

To revolutionize reliability we must establish a solid science foundation based on first principles, predictive, reliability models. This science base must be incorporated into a suite of powerful, yet practical, model-based engineering tools. The most valuable tools will be simulators that can support design-for-reliability, virtual qualification and self-aware products.

5. What a 21st Century, Science-based Reliability Program Might Look Like

Figure 2 shows a proposed science-based, life-cycle program for competitively managing reliability. There are five life-cycle stages to the program:

1. Concurrent R&D. For maximum benefit, predictive failure mode models and powerful engineering capabilities must be available *prior* to starting system optimization and concurrent engineering. This will only be possible if, as indicated in Figure 3, there is a significant reliability R&D program early in the development of a new technology. This

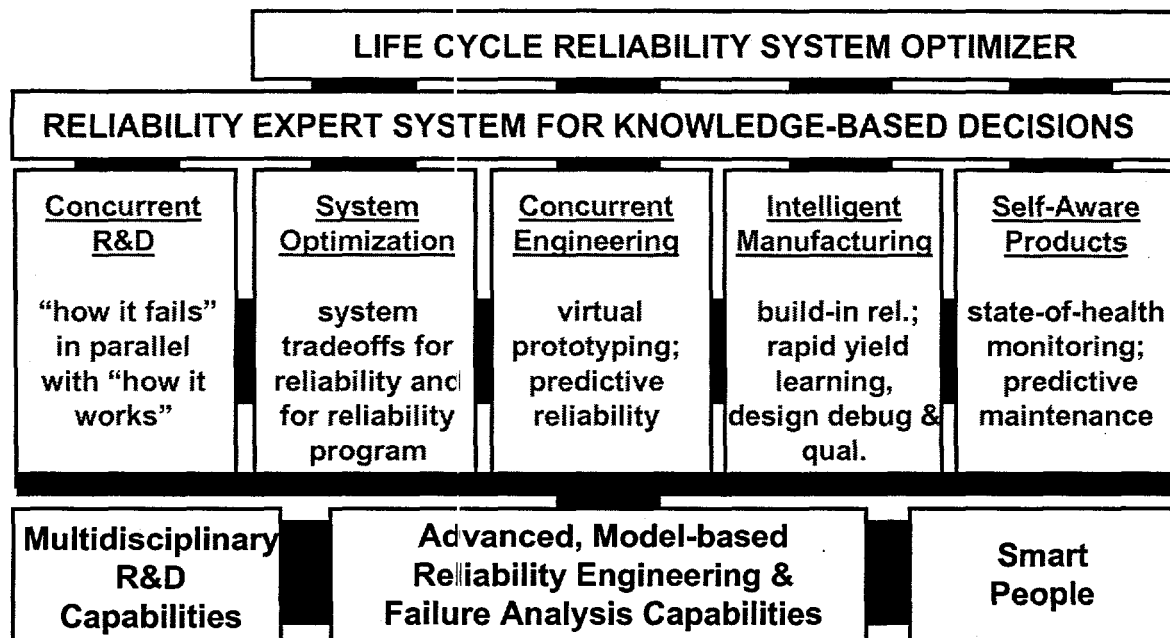


Figure 2. A 21st Century, science-based, life-cycle, reliability program.

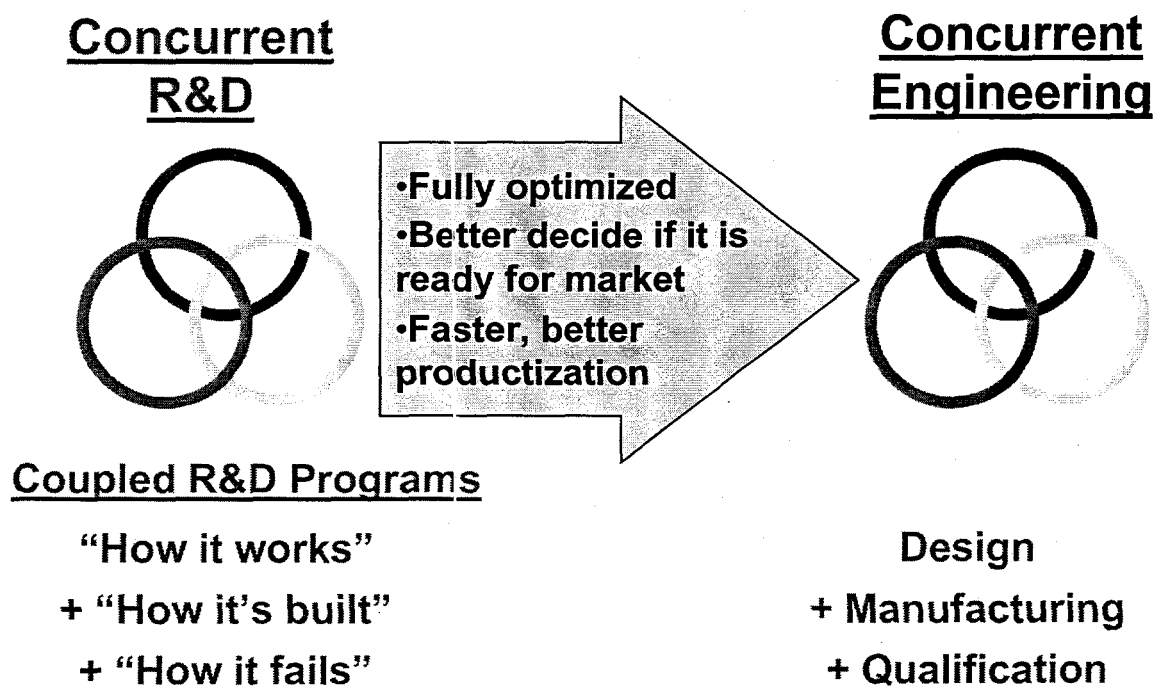


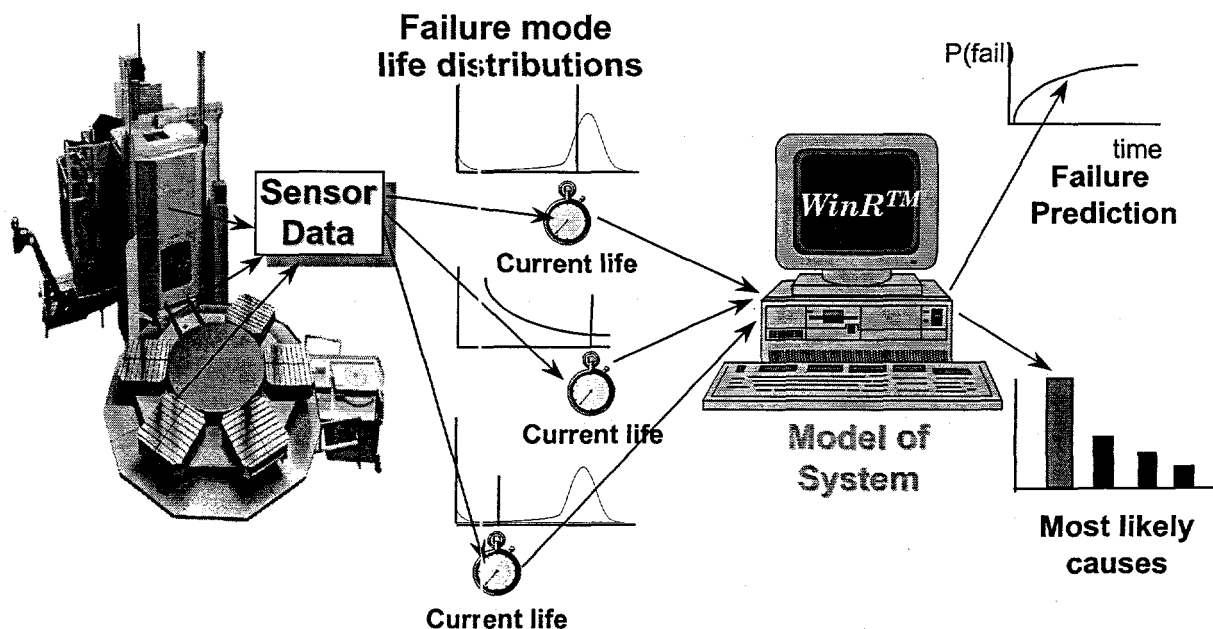
Figure 3. Concurrent R&D is required to fully benefit from Concurrent Engineering.

Concurrent R&D approach will also produce a more robust technology and a better assessment of the technology's readiness for the marketplace. One of the first applications of Concurrent R&D at Sandia is in our development of micromachine technology.

2. System optimization. This involves two activities. Determining the reliability requirements by doing Failure Modes and Effect Analysis, reliability partitioning, etc. In addition, the life-cycle system of reliability activities (e.g., mix of design, manufacturing, and test activities) must be defined and optimized against business metrics.
3. Concurrent Engineering. Reliability issues are addressed and resolved early in the design process. The goal of this and the next phase is to build-in reliability and reduce the dependence on testing in and screening in reliability.
4. Intelligent Manufacturing. Intelligent, model-based process control is designed to reduce defects and process excursions that can lead to early life failures.
5. Self-Aware Products. Products are built with the capability to provide state-of-health monitoring that can provide an early warning of impending failures and can be used for predictive maintenance (Sandia is now working on applying its system reliability tool, WinRTM to predictive maintenance. See Figure 4).

Underlying all of the life cycle phases is a science-based reliability engineering foundation. A multidisciplinary technology base and smart people are required to implement science-based engineering. This is an exceptionally difficult technical challenge.

Finally, overarching the five life-cycle phases are an expert system and a reliability system optimizer. Knowledge is a valuable and expensive commodity that must be captured, and



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Figure 4. Schematic of predictive maintenance using the WinRTM system reliability software.

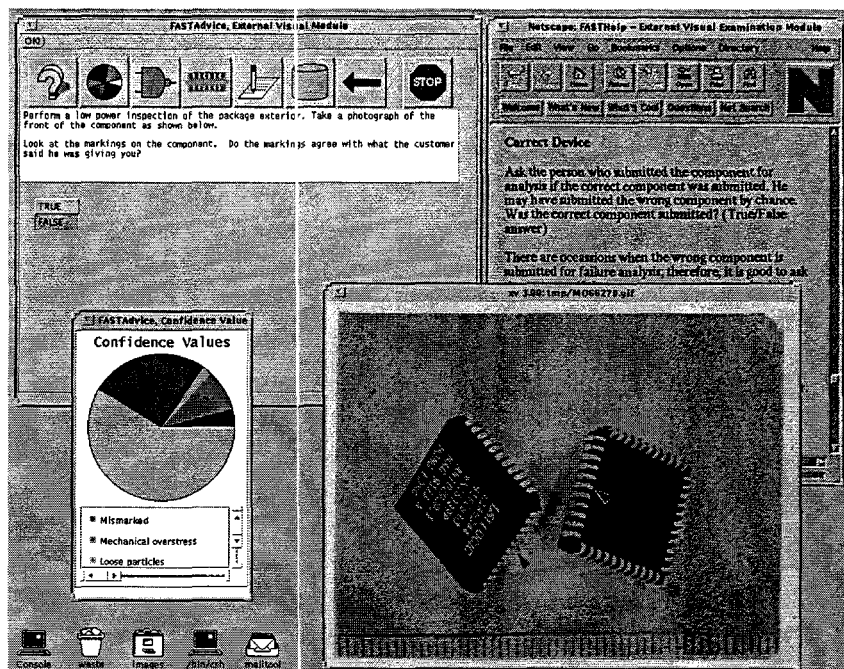


Figure 5. Fast Advice™, Failure Analysis Expert System.

fully utilized, at every stage in the life-cycle. Sandia has developed an expert system FastAdvice™ for integrated circuit failure analysis (see Figure 5). Now we are using this experience to begin development of a robust, extensible, science-based, reliability expert system (REX™). Treating reliability as a system of activities and, as mentioned above, optimizing that system is also very important. At Sandia, we are also looking into designing a computer aided design of reliability systems program (CAD-RELS™).

6. Management of Reliability

Some of the major issues in the management of reliability programs in the 21st Century are summarized in Figure 6. Probably the most important challenge will be staffing. A different, higher-level skill mix (e.g., more knowledge of physics-of-failure) will be required of 21st Century reliability engineers. The engineers need the intellectual capacity to make value adding reliability predictions even when faced with incomplete knowledge of failure modes and with under-powered reliability engineering capabilities. To provide this caliber of technical talent we must establish new education and training programs and need to make a career in reliability more attractive. To meet these educational needs, the University of New Mexico and Sandia are nationally televise graduate courses in science-based electronics reliability each semester. Sandia also supports the University of Arizona and the University of Maryland.

7. Summary

In the 21st Century, we will demand more of our reliability programs. We will need the ability to make accurate reliability predictions that will enable optimizing cost, performance and time-to-market to meet the needs of every market segment. We will require that all of these new capabilities be in place prior to the start of a product development cycle. The management of reliability programs will be driven by quantifiable metrics of value added to the organization business objectives.

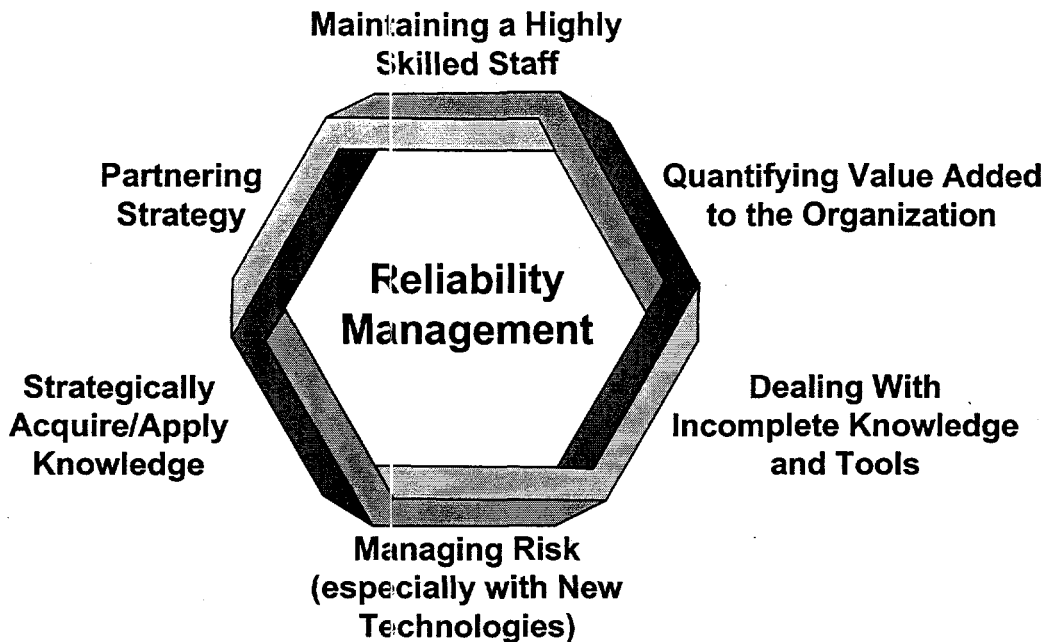


Figure 6. Major challenges in the management of reliability programs.

We urgently require a revolution in reliability engineering comparable to the revolutions that have swept through design and manufacturing engineering. This revolution will be based on a science-based reliability engineering paradigm. Science-based reliability will enable building-in reliability, agile manufacturing, virtual qualification, self-aware products and predictive maintenance. Driven by the needs of its national security mission, Sandia National Laboratories, in collaboration with external organizations, is developing the tech base that will enable science-based reliability engineering.

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The author enthusiastically invites other people and organizations to join in this dialogue about the future of reliability engineering. Comments and suggestions are always welcome. In addition, Sandia National Laboratories is interested in developing strategic partners to develop and apply a science-based approach to reliability engineering.

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