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Reliability: How much is it worth? Beyond its estimation or prediction, the (net) present value of reliability

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Abstract

In this article, we link an engineering concept, reliability, to a financial and managerial concept, net present value, by exploring the impact of a system's reliability on its revenue generation capability. The framework here developed for non-repairable systems quantitatively captures the value of reliability from a financial standpoint. We show that traditional present value calculations of engineering systems do not account for system reliability, thus over-estimate a system's worth and can therefore lead to flawed investment decisions. It is therefore important to involve reliability engineers upfront before investment decisions are made in technical systems. In addition, the analyses here developed help designers identify the optimal level of reliability that maximizes a system's net present value—the financial value reliability provides to the system minus the cost to achieve this level of reliability. Although we recognize that there are numerous considerations driving the specification of an engineering system's reliability, we contend that the financial analysis of reliability here developed should be made available to decision-makers to support in part, or at least be factored into, the system reliability specification.

Keywords: Optimal reliability; Net present value (NPV); Revenue generation; Value of reliability

1. Introduction: expanding the traditional focus of reliability engineering

Reliability and risk analyses have traditionally been conducted in order to provide information for stakeholders as basis for, or aid in, decision-making [1]. Relevant data needed as input, and the techniques to be used, are often dependent on the decision problems at hand [2]. These problems have historically fallen under two broad categories: reliability prediction and reliability improvement—at the component or system level [3].

Reliability prediction is conducted in order to prove that a component or system meets reliability requirements. It can have either a component or a system centric focus, and in practice often bridges between component and system-level analyses. For example, probabilistic risk assessment (PRA) is used to estimate the probability that a system will fail in certain ways (and the consequences of such failure—hence the qualifier *risk* in PRA), given the estimated probabilities of failure for the system components.

Reliability improvement is either done on an ad-hoc basis, for example, by identifying and replacing unreliable components based on after-the-fact operational evidence, or more systematically by using analysis methods such as PRA to identify components and subsystems that have a significant effect on system reliability. The desired system-level reliability can then be obtained by ensuring that these components have the necessary reliabilities, or by using reliability engineering techniques such as redundancy to limit the effect of a single component failure on the system-level reliability.

In this paper, we focus neither on reliability prediction nor on reliability improvement. Instead, we propose to connect an engineering concept, reliability, with a financial and managerial concept, the net present value, or NPV. In order to build this connection, we first explore the impact of a system's reliability on the flow of service the system can provide over time—for a commercial system, this translates into the system's revenue-generating capability. We then use traditional discounted cash flow techniques to capture

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the impact of the system reliability on its financial worth, or NPV. For simplification, we call the results of our calculations the ‘value of reliability’.

The analyses we develop in this paper allow designers, in part, to identify ‘optimal’ levels of reliability for engineering systems from a financial standpoint. How is that?

Conceptually, the process for deciding how much reliability is required from a system (i.e. system reliability specification) involves on the one hand an assessment of the value of reliability—how much is it worth to the system’s stakeholders—and on the other hand, and assessment of the ‘costs’ of reliability. In this work, we focus on revenue-generating systems—such as communication satellites or deep-sea cable systems—that have negligible risk of causing injury or loss of life when they are operational (questions of value of human life are very complex and sensitive, and are beyond the scope of this work). By identifying the impact of reliability of such systems on their NPV (the value of reliability minus the cost of obtaining it, hence the ‘net’ value in the NPV), the framework and analyses developed in this paper provide (financial) information for decision-makers to support in part the reliability specification requirement.

2. Motivation: choices and trade-offs in lieu of ‘infinite reliability’

‘Infinitely reliable’ components or systems do not exist. Failure will occur. It can, however, be ‘postponed’ or delayed in a number of ways. For example, more reliable and expensive components can be used instead of a generic-of-the-shelf component, thus in effect delaying the time-to-failure, or alternatively, redundant components can be used to improve the equivalent reliability—for the additional cost of the redundant component(s). At the system level, preventive maintenance for example can be performed to reduce the probability that the system will fail while in service. These approaches, along with other reliability improvement techniques, can conceptually be viewed as delaying a component or a system’s time-to-failure, and gaining additional operational time. If we view in a system the flow of service (or utility) it provides over time, then we can map this ‘additional operational time’ from improved reliability into an incremental value to the system, thus capturing the value of reliability. This is illustrated in Fig. 1.

However, improved reliability often requires additional resources (e.g. more expensive components) and comes at a price: for example, the preventive maintenance that was mentioned in the previous paragraph requires downtime or loss of productivity in the short-term.

A general theme emerges from the previous observations, namely that since ‘infinitely reliable’ components or systems do not exist, reliability specification requires choices and trade-offs. When the reliability requirements are not imposed by regulators (for example, based on the public’s ‘acceptable’ level of risk), or by market conditions, system designers, in deciding how much reliability is needed, must assess how much reliability is worth and how much they are willing to ‘pay’ for it.

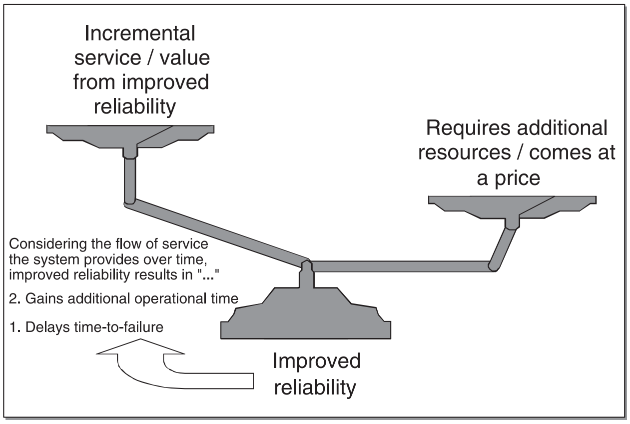

Fig. 1. Improved reliability trade-off: additional reliability comes at a price, but it delays a system’s time to failure and therefore enables additional utility to be derived out of the system. How much reliability is needed implies an assessment of how much it is worth and how much it costs.

This paper addresses precisely this question and contributes a framework that allows designers to assess the (net) value of the reliability of revenue-generating systems, thus in effect providing financial information for decision-makers to help identify ‘optimal’ levels of reliability for engineering systems. As was mentioned previously, systems that have potential to cause injury or loss of life are not considered in this work.

3. Reliability, revenue generation, and present value (PV)

We consider the case of a non-repairable system that can generate $u(t)$ dollars per unit time. This is the expected revenue model of the system or the flow of service it can provide over time. In this simple case, the system has one failure mode, it is either functioning or failed (there are no partial failures), it is not maintainable, and is characterized by a failure rate $\lambda(t)$. We discretize the time after the system is operational into small ΔT bins over which $u(t)$ and $\lambda(t)$ vary little and can be considered constant:

$$\begin{cases} u_n = u(n\Delta T) \approx u[(n+1)\Delta T] \\ \lambda_j = \lambda(j\Delta T) \approx \lambda[(j+1)\Delta T] \end{cases} \tag{1}$$

In order to simplify the indexing, we consider that the revenues the system can generate between $(n-1)\Delta T$ and $n\Delta T$ are equal $\$u_n\Delta T$.

Assume the system is still operational at time $(n-1)\Delta T$, during the following ΔT, it can either remain operational and generate $\$u_n\Delta T$, or fail and generate $\$0$. The probability that the system will fail between $(n-1)\Delta T$ and $n\Delta T$ knowing that it has been operational until $(n-1)\Delta T$ is