Lean Reliability Engineering

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Abstract. Many reliability engineering activities practised today cannot contribute to the objective of reliability engineering, which is the prevention of failure. Lean is a management philosophy with the objective of maximising value by removal of waste from all activities. Waste is defined as any non-value added activity or process. Can lean be applied to reliability engineering?

This paper starts with a brief discussion on the essence and practice of both reliability engineering and lean. It provides a definition of value in the context of reliability engineering, and applies this definition to identify categories of reliability engineering activities which can be considered as waste. It is argued that lean can (and should) be used during the development of a Reliability Program Plan to select only value added activities for execution.

Introduction

The discipline of reliability engineering, which developed rapidly after the 2nd World War, has not kept pace with modern technology. Many reliability engineering activities practised today are outdated, misleading, or even fundamentally flawed. This results in the execution of activities which cannot contribute to the primary objective of reliability engineering, which is the prevention of failure. What is the objective of performing these activities?

Lean is well-known as management philosophy with the primary objective of maximising value to the customer by removal of waste from all activities. A fundamental concept in lean is thus the creation of value through the elimination of waste, which is defined as any non-value added activity or process. If a specific reliability engineering activity does not add value to the design and production of failure-free products and systems, it may be considered as waste, and should therefore not be performed.

What is reliability engineering?

Reliability engineering is everything you do today to prevent product failure tomorrow.

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The essence of reliability engineering

Reliability, according to the conventional definition, is “the probability that an item will perform a required function without failure under stated conditions for a stated period of time.” (O’Connor and Kleyner 2012). This definition combines two distinct disciplines, namely statistics (e.g. probability) and engineering (e.g. required product or system functions, operating conditions and period of time).

Unfortunately, the focus on probability in this definition has over the years resulted in major emphasis on various aspects of mathematics and statistics in reliability engineering (Barnard 2015). This emphasis is understandable given the technology available when reliability engineering activities were originally developed. Many electrical and electronic parts at that time failed due to quality problems or due to wear-out, contributing to today's misleading beliefs that all parts have failure rates, that system failures are caused by part failures, etc.

Today, many consumer, industrial and defence products and systems are often replaced by customers and users due to technological obsolescence (e.g. computers). Users of even complex products and systems have become accustomed to extremely high reliability (e.g. motor vehicles). We clearly need a new definition for reliability. This definition should be based on the basic principles of reliability and be descriptive of the very high levels of reliability achieved by world-class companies today. Such a definition requires a fundamental understanding of the objective of reliability engineering.

In 1982, Ralph Evans wrote "What is the goal of reliability engineering? We need to distinguish between tasks that are often useful way stations and the ultimate goal. The ultimate goal is to have the product meet the reliability needs of the user insofar as technical and economic constraints allow. The biggest difficulty with that goal is that it's not readily measureable - and for some people, if you can't measure it, it is just so much claptrap. The ultimate goal surely is not: To generate an accurate reliability number for the item." (Evans 1982). The primary objective of reliability engineering is thus not the calculation or prediction or measurement of a 'probability' as given in the conventional definition of reliability.

In 1995, Philip Crosby wrote that "All non-conformances are caused. Anything that is caused can be prevented." (Crosby 1995). These two short sentences, originally written from a quality perspective, are also applicable to the fundamentals of reliability engineering. It suggests that all product or system failures are caused, and that all these failures can be prevented.

In 2011, Norman Pascoe wrote "All failures in electronic equipment can be attributed to a traceable and preventable cause and may not be satisfactorily explained as the manifestation of some statistical inevitability." (Pascoe 2011). Once again, it is evident that failures are caused, and that failures can be prevented.

Based on these statements, and applying common sense to real life experience, reliability and reliability engineering may be defined as follows (Barnard 2008):

- Reliability is the absence of failures in products.
- Reliability engineering is the management and engineering discipline that prevents the creation of failures in products.

These simple definitions imply that a product is reliable if it does not fail (during its expected life under the full range of conditions experienced in the field), and that this failure-free state can only be achieved if failure is prevented from occurring. When product failure occurs and root cause analysis is performed, it becomes evident that failures are created, primarily due to errors made by people. These include design and production personnel, as well as operators and maintenance personnel.

What is required to prevent failure? Firstly, engineering knowledge to understand the applicable failure mechanisms, and secondly, management commitment to mitigate or eliminate them. Proactive prevention of failure should be the primary focus of reliability engineering, and never reactive failure management or failure correction. Reliability engineering activities change from 'proactive' during design and development to 'reactive' during production and especially during operations. Reactive reliability engineering should be avoided due to the very high cost of corrective actions which may be required (e.g. redesign, product recalls, etc.).

It is important to understand that reliability is a non-functional requirement during design and development, and that it becomes a characteristic of a product or system during operations. Product development is an iterative process where design is followed by verification. 'Analysis' and 'test' are two primary verification methods used in engineering. Reliability engineering activities to perform reliability analyses and tests are well-documented in various text books on reliability engineering (O'Connor and Kleyner 2012). Product and system reliability is the result of many management and technical decisions taken during all development stages (i.e. concept, definition, design and production).

The practice of reliability engineering

Reliability engineering activities are often neglected during development, resulting in a substantial increase in risk of project failure or customer dissatisfaction. It is therefore recommended that reliability engineering activities be formally integrated with other systems engineering technical processes. A practical way to achieve integration is to develop a Reliability Program Plan at the start of the project.

Appropriate reliability engineering activities should be selected and tailored according to the objectives of the specific project, and should be documented in the Reliability Program Plan. The plan should indicate which activities will be performed, the timing of the activities, the level of detail required for the activities and the persons responsible for execution of the activities.

ANSI/GEIA-STD-0009, *Reliability Program Standard for Systems Design, Development, and Manufacturing*, can be referenced for this purpose (Information Technology Association of America 2008). This standard supports a system life cycle approach to reliability engineering, and consists of four parts with the following objectives:

- Understand Customer / User Requirements and Constraints
- Design and Redesign for Reliability
- Produce Reliable Systems / Products
- Monitor and Assess User Reliability

Reliability engineering activities can be divided into two groups, namely engineering analyses and tests, and failure analyses. These activities are supported by various reliability management activities (e.g. design reviews, electronic part derating guidelines, preferred parts lists, preferred supplier lists, etc.).

Engineering analyses and tests refer to traditional design analysis and test methods to perform, for example, load-strength analysis during design. Included in this group are finite element analysis, vibration and shock analysis, thermal analysis and measurement, electrical stress analysis, wear-out life prediction, HALT (Highly Accelerated Life Testing), etc.

Failure analyses refer to traditional reliability analyses to improve understanding of cause-and-effect relationships. Included in this group are FMEA (Failure Mode and Effects Analysis), FTA (Fault Tree Analysis), RBD (Reliability Block Diagram) analysis, systems modelling and simulation, root cause failure analysis, etc.

Figure 1 indicates a few relevant aspects which may be used to develop a Reliability Program Plan for a specific project (Walden et al. 2015).

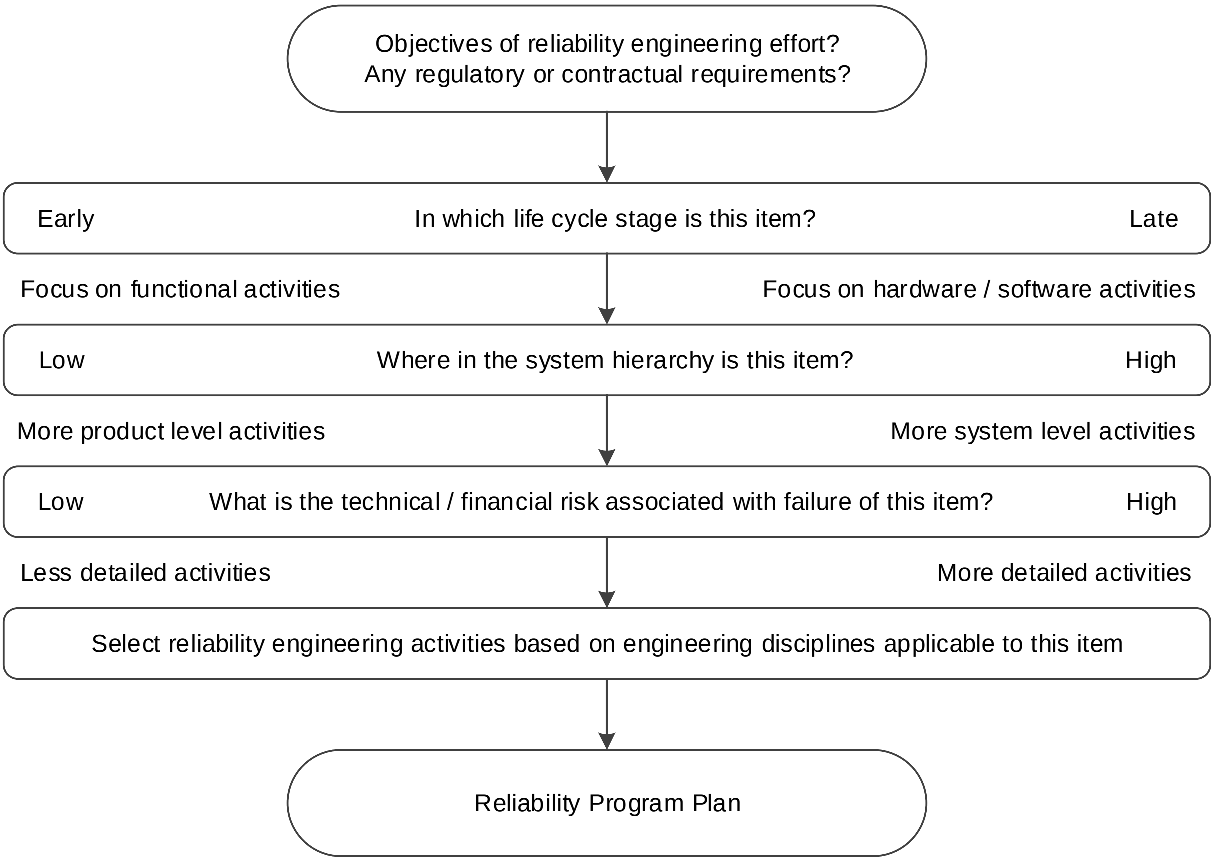

Figure 1: Reliability Program Plan development

What is lean?

The core idea is to maximize customer value while minimizing waste. Simply, lean means creating more value for customers with fewer resources. The ultimate goal is to provide perfect value to the customer through a perfect value creation process that has zero waste.

Lean Enterprise Institute

The essence of lean

Lean is well-known as management philosophy with the primary objective of maximising value to the customer by removal of waste from all activities. The origins of lean can be found at Toyota, and more specifically the Toyota Production System, which is seen as major contributor to Toyota's success in the automotive market. This production system dramatically reduced vehicle production time and costs, and simultaneously increased product quality and reliability. "The Toyota system developed products in much less time with many fewer hours of engineering, products that cost less to manufacture and that had fewer defects as reported by customers." (Morgan and Liker 2006).

The 'father' of lean at Toyota, Taiichi Ohno, first published his views in a Japanese book called "Toyota Seisan Hoshiki" in 1978. This book, which was translated into English in 1988 and published as the "Toyota Production System", gave English speaking readers insight into these fundamentals. He wrote that the "most important objective of the Toyota system has been to increase production efficiency by consistently and thoroughly eliminating waste." (Ohno 1988).

However, it was the 1990 book titled "The Machine That Changed the World" which made the lean philosophy generally known in many industries (Womack, Jones and Roos 2007). While Ohno's original book describes the <u>production system</u> at Toyota, a book published in 2006 by Morgan and Liker provides more insight into the <u>product development system</u> at Toyota (Morgan and Liker 2006).

The concepts of lean have been widely applied in many manufacturing industries, and in many other sectors such as logistics and distribution, services, retail, healthcare, construction, maintenance, and even government (Lean Enterprise Institute 2014). More recently, and important in the context of reliability engineering, lean has been introduced to new product development and to systems engineering. Lean Systems Engineering, which is today seen as an emerging field representing the synergy of systems engineering and lean, is defined as "the application of lean wisdom, principles, practices and tools to systems engineering in order to enhance the delivery of value to system's stakeholders." (Oppenheim 2011).

The concepts of 'value' and 'waste' are fundamental in lean. The overall objective is to minimise waste in order to maximise value. There is thus an inverse relationship between value and waste; more waste means less value (and vice versa). Waste is therefore simply anything which does not create value. "In short, lean thinking is *lean* because it provides a way to do more and more with less and less." (Womack and Jones 2003). While Ohno specifically referred to waste removal, some authors suggest that lean should not focus on waste, but rather on value. The focus on waste has caused lean to be thought of (and even defined) in terms of removing waste (Browning 2003). But what is value and what is waste?

The practice of lean

Lean principles

The practice of lean is often described by the so-called lean principles, originally described as the definition of value, mapping of the value stream, flow, pull and perfection (Womack and Jones 1996). A sixth principle was later added to ensure adequate consideration for respect for people in any lean implementation (Oppenheim 2011). The implementation of lean techniques therefore consists of the following:

1. Define value from the viewpoint of the customer (either external or internal).
2. Identify and map all steps in the value stream (eliminating waste whenever possible).
3. Ensure that the work 'flow' through these steps without delays or rework.
4. Establish 'pull' from the next upstream activity.
5. Pursue 'perfection' of all activities and processes.
6. Introduce 'Respect for People' in all work activities.

These steps are repeated as continuous improvement process until a state of perfection is approached where value is created without any waste, as shown in Figure 2 (Lean Enterprise Institute 2014).

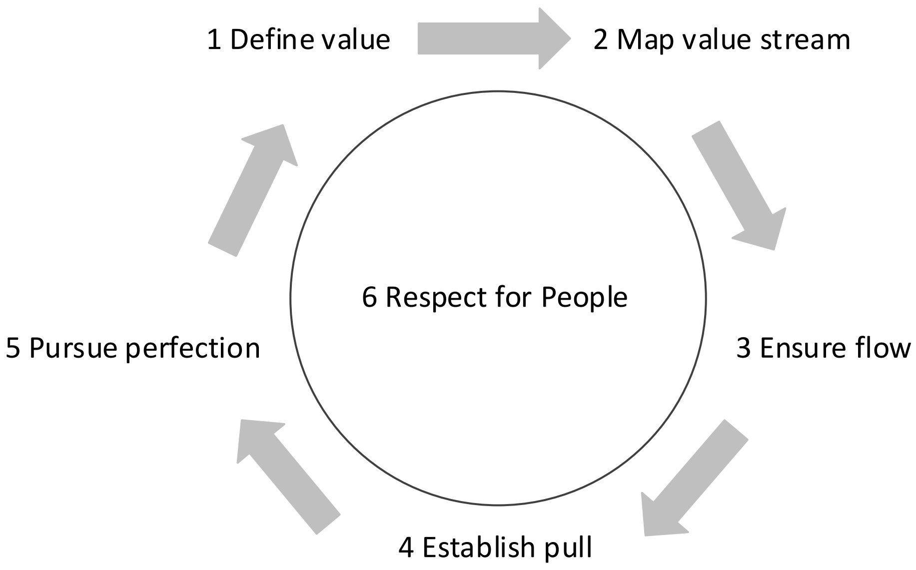

Figure 2: Lean principles as continuous process

The accurate definition of value and subsequent identification of waste are essential steps for successful lean implementation. Value and waste may be relatively easy to identify and define for a manufacturing process, but it may be much more difficult to define value and identify waste for product development.

Value

Value of a product or system to a customer can, in general terms, be defined as the ratio between benefits and costs. Benefits obviously depend on customer perceptions and preferences. Of significant importance, is that the value of a product or system is always determined by the customer, and not by the developer or producer. It is important to note that the customer is not necessarily the end user; it can be anybody receiving a service or product in a supply chain.

Waste

Lean classifies all work activities into three categories (Oppenheim 2011):

- Value added activities, which have to satisfy the following three conditions:
    - Transform information or material, or reduce uncertainty.
    - Customer is willing to pay for (that is, if customer understood details, he would approve of this activity).
    - It is done right the first time.
- Required (also called necessary) non-value added activities, which do not meet the definition of value added activities, but which cannot be eliminated because they are required by law, contract, etc. (also called necessary waste).
- Non-value added activities, which consume resources and create no value (also called pure waste).

Ohno classified waste in manufacturing into the following seven categories[1] (product development examples shown in parenthesis):

- Overproduction (e.g. producing more than the next process needs)
- Waiting (e.g. waiting for information)
- Transportation (e.g. moving information around)
- Processing (e.g. doing unnecessary processing on a task, or an unnecessary task)
- Inventory (e.g. build-up of information that is not being used)
- Motion (e.g. excessive motion during task execution)
- Defects (e.g. inspection or correction of errors made)

'Uncertainty reduction', as part of the value added category, is extremely important in the context of this paper, since reliability engineering is in essence concerned with the prevention of highly uncertain events (i.e. failures).

Lean applied to reliability engineering

Reliability in a product is not what you put into it.
It is what the customer gets out of it.[2]

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The application of lean to reliability engineering implies that the execution of reliability engineering activities should focus on the creation of value to the customer. Alternatively, it means that the execution of reliability engineering activities should not be considered as waste. We therefore need a definition on the value of a reliability activity. A closer look at the execution of typical reliability engineering activities reveals that a specific activity can:

- Identify a design or process improvement opportunity (i.e. creates value), or
- Confirm the absence of a design or process improvement opportunity (i.e. creates value), or
- Provide no useful information (i.e. creates no value).

Reliability engineering as process is analogous to the process used by medical practitioners. Many people regularly consult medical practitioners, whether they are ill or not. Except for performing medical procedures, physicians examine patients (by using some analysis or test method) to identify an existing disease (i.e. diagnosis), or to confirm the absence of abnormalities which can lead to future disease. Both these outcomes are valuable from the patient's viewpoint (and therefore they are willing to pay for it). This is exactly how reliability engineering is practised. A product or system is analysed and tested (hopefully during development) to identify potential critical or catastrophic failure modes which can be corrected prior to operations, or to provide evidence of the absence of those failure modes.

[1] Ohno used slightly different terms for these categories of waste.
[2] Adaptation of quotation on quality by Peter Drucker.

Value in reliability engineering is therefore created by:

- Performing an activity which, through any design or process improvement, results in the elimination (or reduction in the probability) of product failure, or
- Performing an activity which, through confirmation of the absence (or low probability) of potential failure modes, results in a reduction in uncertainty.

Figure 1, which is proposed to facilitate the development of a Reliability Program Plan, does not refer to value of a specific reliability engineering activity. From a lean viewpoint, we have to include the question "What value can be added by the specific activity?" to the diagram, as shown in Figure 3. If a specific activity does not contribute to the ultimate goal of designing and producing failure-free products and systems, it should simply not be performed.

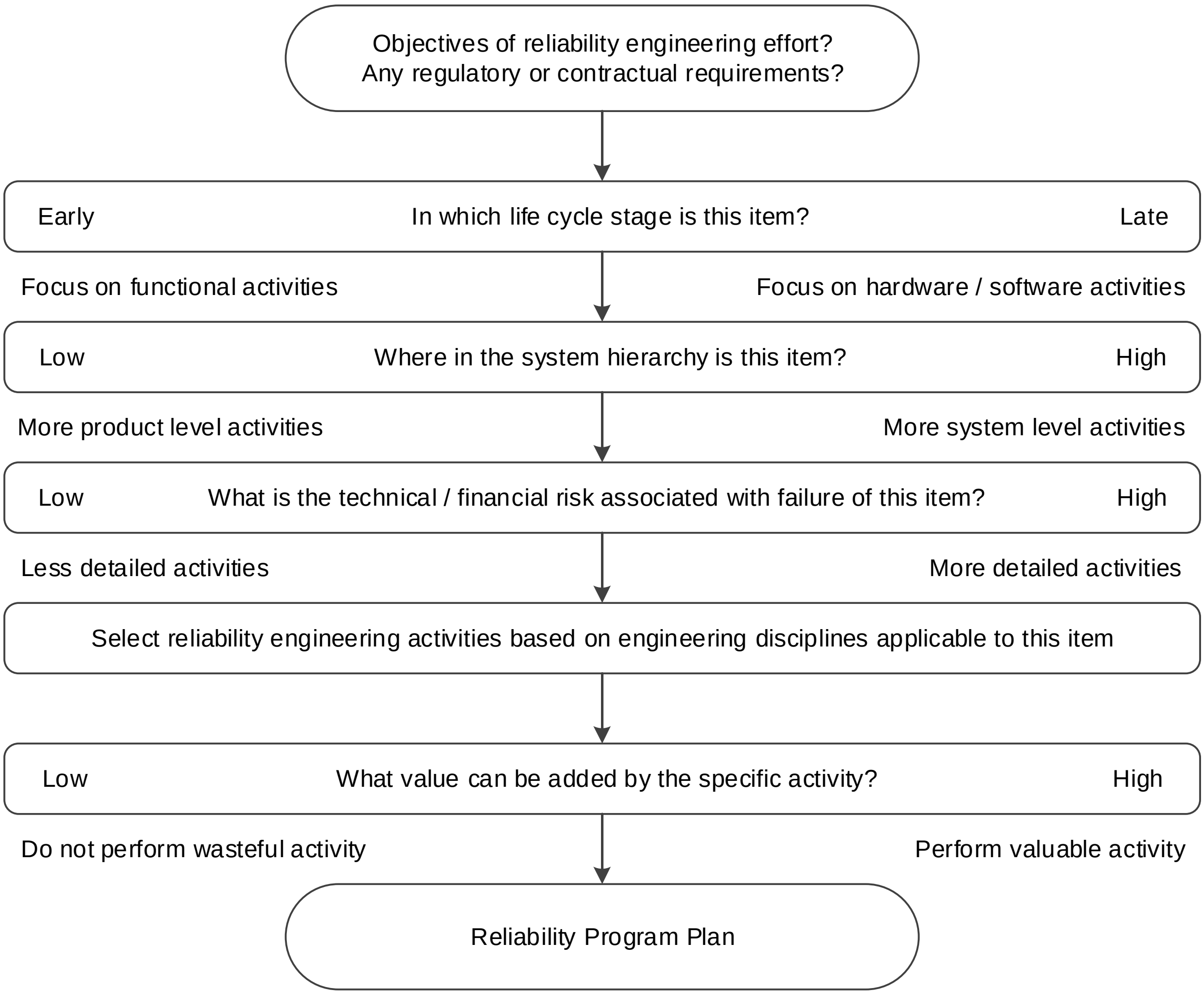

Figure 3: Lean Reliability Program Plan development

Apart from the general sources of waste as defined by lean (overproduction, waiting, transportation, processing, inventory, motion and defects), there are specific categories of waste in reliability engineering. These can be grouped into categories relating to the selection and execution of reliability engineering activities (Barnard 2015).

Selection of reliability engineering activities

1 Selection of fundamentally flawed activity

Some reliability engineering activities are fundamentally flawed, and cannot contribute to the primary objective of reliability engineering. These activities can never add value, and are examples of pure waste. The most prominent activity in this category is reliability prediction based on any 'parts count' or 'part stress' method such as Mil-Hdbk-217 (and all derivatives thereof). It is simply not possible to determine product reliability by merely adding part failure rates from any published document. The only valid reliability prediction is for wear-out failure modes, where the applicable failure mechanisms are well understood. Reliability demonstration based on Mil-Hdbk-781 is another example of a fundamentally flawed activity. Note that both correct and incorrect execution of these activities are irrelevant, and will in both cases contribute to waste.

2 Selection of incorrect activity

Reliability engineering activities should be selected and tailored according to the objectives of the specific project (as illustrated by Figure 3). Aspects such as complexity, technology maturity, life cycle stage, failure consequence, etc. should be considered during the selection process. If incorrect activities are selected for execution, it will certainly contribute to an increase in waste. Activities which may be considered as non-value adding (even when correctly executed), include the following:

- FMEA (when FTA should rather be performed due to potential safety aspects)
- Reliability block diagram analysis (when performed on series systems (i.e. no redundancy))
- Fault tree analysis (when performed on series systems (i.e. without using AND gates))
- Thermal analysis (when performed on low-power electronic designs)

Execution of reliability engineering activities

1 Execution of activity at incorrect time

Execution of reliability engineering activities at the incorrect time during product or system development is a major contributor to waste. Incorrect time means that the activity is performed too early, or too late. Product development is an iterative process, where design is followed by verification, which may result in redesign, etc. For obvious reasons, a specific reliability analysis can only be performed after a specific design cycle has been completed, and a reliability test can only be performed after a prototype has been manufactured. If either of these activities is performed too early, the analysis or test may provide incomplete or even invalid information, and may have to be repeated at a later stage.

A more serious (and frequent) problem seen in industry is that reliability activities are performed too late during development. Due to ever increasing pressure on time scales, there is usually a short 'window of opportunity' to perform reliability engineering activities between design and production. "Reliability engineering often becomes a 'numbers game' after the real game is over. Reliability cannot be economically added after the system has been conceived, designed, manufactured and placed in operation." (Billinton).

2 Incorrect execution of activity

Reliability engineering activities that are normally considered as valuable (e.g. FMEA, HALT, etc.), are non-value adding when they are not correctly executed, or when incorrect assumptions are made during their execution. Execution of activities by the incorrect people (e.g. a logistics engineer performing a Design FMEA, an electronic design engineer performing finite element analysis or thermal analysis, etc.) is often encountered in practice, and may be a major contributor to waste. Activities which may be considered as non-value adding due to incorrect execution include the following:

- Reliability block diagram analysis (when using MTBF values published in part manufacturer's data sheets)
- Derating analysis (using part maximum ratings listed for 25°C ambient temperature)
- FMEA (without in-depth understanding of cause of failure modes)
- Reliability analysis based on hardware only (i.e. ignoring software)
- Weibull analysis (ignoring requirements for valid data analysis)
- HALT (without design or process improvement when required)

Conclusion

The reduction (or preferably the elimination) of waste is a key principle of lean. Any reliability engineering activity which does not contribute to the primary goal of designing and producing failure-free products and systems may be considered as waste, and should not be performed. Lean is thus applicable to reliability engineering, and lean principles should be considered during the development of any Reliability Program Plan.

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Biography

Albertyn Barnard received the degrees M. Eng. (Electronics) and M. Eng. (Engineering Management) from the University of Pretoria (South Africa). He has provided consulting services in systems and reliability engineering to the defence, nuclear, aerospace, utilities and commercial industries since 1982. He provides training in reliability engineering to industry and at post-graduate level at the University of Pretoria. He has presented numerous technical papers at symposia, and won the Best Paper Award at the 2004 INCOSE SA conference (South Africa), the Gold Award at the 2009 International Applied Reliability Symposium Europe (Spain), as well as the Silver Award at the 2012 International Applied Reliability Symposium Europe (Poland).

He has been a member of the management committee of INCOSE South Africa for a number of years, served as President of INCOSE South Africa in 2008, and established the INCOSE Reliability Engineering Working Group in 2011. He is currently leading this international working group, which focuses on reliability engineering from a systems engineering viewpoint.

His company, Lambda Consulting, specialises in reliability engineering activities applicable to the development stages of products and systems, with emphasis on reliability analysis of electronic design and HALT (Highly Accelerated Life Testing). Lambda Consulting established the first commercial HALT laboratory in South Africa in 2008.