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Review Article

What is the Reliability of the Reliability Function?

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Submission: November 13, 2018; **Published:** November 29, 2018

Abstract

According to Knezevic [1] the purpose of existence of any functionable system is to do function ability work, which is considered to be done when the expected measurable function is performed through time. However, experience teaches us that in-service life of functionable systems is frequently beset by undesirable in-service disturbances resulting from a variety of physical mechanisms (overstress, wear out, natural phenomena and human interventions), some of which result in hazardous consequences to: the users; the natural environment; the general population and businesses. During the last sixty years, Reliability Theory has been used in an effort to predict these occurrences of undesirable in-service disturbances (frequently called failures). However, mathematically and scientifically speaking, the accuracy of these predictions, at best, were only ever valid to the time of the occurrence of the first undesirable in-service event, which is far from satisfactory in the respect of its expected life. Consequently, the main objective of this paper is to raise the question, how reliable are reliability predictions, based on the Reliability Function, in terms of mathematical and physical truth?.

Keywords: Reliability theory; Reliability function; Mathematical truth of reliability function; Physical truth of reliability function; Accuracy of reliability function

Introduction

According to Knezevic [1] the purpose of existence of any functionable system is to do function ability work, which is considered to be done when the expected measurable function is performed through time, like energy produced, guests hosted, vehicles traversed over a bridge and so forth.

However, experience teaches us that operational life of functionable systems is frequently beset by undesirable interruptions resulting from:

a. Internal actions, caused by physical and chemical phenomena like corrosion, fatigue, creep, abrasion, wear and similar [2-6]

b. Environmental actions, caused by natural phenomena, like: lightning, snow, rain, sand, fog, wind, solar radiation, earthquakes, tsunami and so forth [7-17].

c. Human induced actions, such as inadequate provision of operational and maintenance resources (personnel, fuel, spares, facilities, tools, etc.), errors in the execution of tasks (operational, maintenance, storage, transportation, and others), organizational issues, regulatory bodies and similar [16-20].

Needless to say, that the above-mentioned in-service interruptions result in:

a. Hazardous consequences to the users, the natural environment and the general population, like a few major accidents in nuclear energy production (Three Mile Island (1978 in USA), Chernobyl (1986 in USSR), Fukishima (2011 in Japan), Deepwater Horizon oil spill (2010, USA), NTPC power plant explosion (2017 in India) and numerous others.

b. Business consequences in private sector due to loss of revenue.

For example, closure of hotels, hospitals, bridges, motorways and numerous other business or public buildings generate the cost to:

The property owners due to:

i. Loss of income generated by renting properties.

ii. Poor customer relationships.

iii. Increased demand for support resources (spares, tools, equipment, etc.).

iv. Demand for skilled and trained personnel required to deal with the consequences of closure.

v. Costs arising from booking of substitution properties.

The customer too, due to:

i. Disrupted plans.

ii. Missed business opportunities.

iii. Missed "non-repeatable" family and personal events.

iv. Health deterioration due to postponement of medical treatments.

The necessity for the reduction in occurrences of undesirable in-service disturbances started with the advanced developments in military, aviation and nuclear power industries, where the potential consequences could be significant.

The Birth of Reliability Theory

During 1950s, Reliability Theory was "created", mainly by mathematicians and statisticians. Hence, it was based on mathematical theorems and statistical methods rather than on scientific theories and methods. Massive attempts were made to further the applications of the existing mathematical, statistical and analytical methods on the data collected without any attempts for understanding of the physical mechanisms that caused the occurrences of undesirable in-service disturbances.

Not surprisingly, deterministically educated mechanical electrical, civil, chemical and all other types of engineers and managers experienced fundamental difficulties in understanding Reliability Theory. The reason for that is very simple. Probability, as a main building block of reliability cannot be seen or measured directly, unlike numerous measurable physical properties. For example: pressure, temperature, volume, weight of a component can be measured directly. Then, by using appropriate mathematical manipulations, accurate predictions of the corresponding properties of a system, constructed of parts with those properties, can be obtained. Moreover, occurrences of undesirable in-service interruptions are also clearly manifested and physically observed phenomena. And yet, the concept of reliability is abstract and immeasurable. It cannot be seen on the component/system considered. In fact, it serves as an abstract property that obtains a physical meaning only when a large sample of components/ systems, of the same type, is considered.

Reliability Function

To support the above presented observations regarding Reliability Theory, the fundamental measure of reliability, reliability function, will be used and analyzed. It is widely accepted that Reliability R(t) is defined as the probability (P) that a considered entity will operate without an undesirable in-service event taking place during a stated period of time (t), when operated in accordance with defined parameters, thus:

R(t)=P (an undesirable in-service event will not take place before time t)

To fully appreciate the meaning of the reliability function it is necessary to stress that it does not address a question, "will undesirable in-service disruption take place or not, during a given interval of time ". It is impossible to know the precise answer to this question, until after the fact (e.g. historical records). However, the reliability function quantitatively defines the proportion of components or systems, of the type considered, that will not experience an undesirable in-service disturbance during a given interval of time. The reliability functions for a component or a system are briefly examined below.

Reliability function of a component

Mathematically, the above generic definition for the reliability function, applied to a single component, is fully defined by the following expression [21]:

$$R(t) = P(TTF > t) = \int_t^\infty f(t)dt, \qquad t \ge 0$$

where: f(t) is the probability density function of the ransdom variable known as the Time to Failure (TTF) of a component. In this paper the expression undesirable in-service disturbance is used for TTF, as it incorporates physical phenomena like volcanic eruptions, bird strikes, cosmic weather, operator error, ice crystal formation (icing), tsunami, shark bite, incorrect installation, "fine sand" and many others that prevent a component from functioning and are not attributable to the "Time To Failure" of the component, as perceived by their designers.

Reliability data of components considered are fully defined through the numerous well-known probability distributions (Weibull, Normal, Exponential, Log-normal and similar). Current aviation and defense industries best practices are premised on the reliability of components being defined by their manufacturers through a constant failure rate, l, which forces all interested parties to express the reliability function in the form. Although these practices are accepted as a part of the contractual arrangements between producers and users, the accuracy of their predictions is never confirmed during the in-service operation. This is regrettable as acceptance of this approach totally negates the existence of physically observable and well-understood processes like: fatigue, corrosion, wear, abrasion, creep and similar [4,6,22,23].

Finally, it is necessary to stress that each component could be exposed to many mechanisms that are competing to generate an undesirable in-service disturbance.

Reliability function of a system

The reliability function for a system, s(t), is determined by the reliability functions of the constituent components and the way that their undesirable in-service interruptions impact the reliability performance of the system. For example, the reliability function for the hypothetical system, whose reliability block diagram is presented in Figure 1, is fully defined by the following mathematical expression [4]:

$$R_S(t) = P(TTF_S > t) = R_A(t) \times \{1 - [1 - R_B(t)][1 - R_C(t)]\}, \qquad t \ge 0$$

Given that the reliability functions of constituent components A, B and C, are known, it is possible to plot the reliability function for a system and calculate the probability of an undesirable in-service event not taking place during a given interval of future time, t. A typical example may be as shown in Figure 2, where the time is measured from the introduction of a system into service.

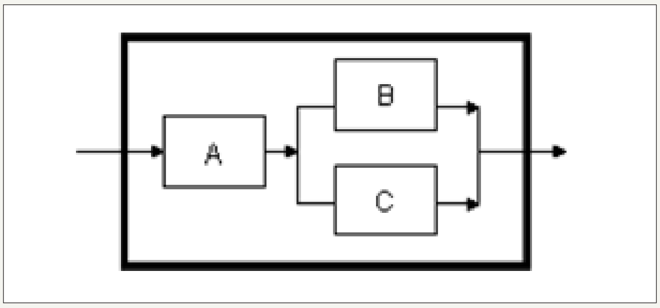

Figure 1: Reliability block diagram for a hypothetical system whose un-desirable in-service event will take place either when a component A malfunctions or components B and C malfunction.

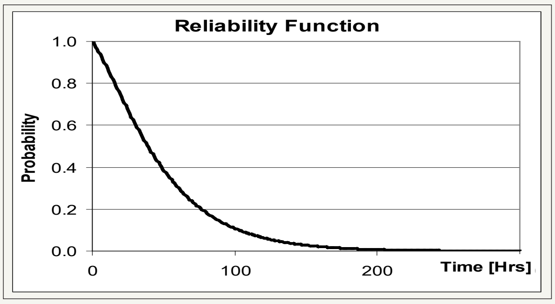

Figure 2: Reliability Function for a system.

The above two equations briefly summaries the essence of the concept of the reliability function, as perceived through Reliability Theory, in which the main concern is a prediction of the behavior of the system until the occurrence of the first undesirable in-service event.

Mathematical Truth of a Reliability Function

Being educated to use deterministic mathematical expressions for all engineering calculations and predictions, which predominantly had a single numerical outcome; it took the author over a decade to properly understand the fundamental physical meanings of the mathematical interpretation of the reliability of systems defined by the system reliability function.

The journey of "discovery" started after the reading of the treaty on mathematical truth by Dubi [24]. It states that mathematics creates a natural trichotomy by dividing all the statements into three exclusive realms or groups:

a. "True" statements, namely, those that can be proven from the axioms

b. "False" statements, those that contradict any of the axioms

c. "Not related"-those that do not result from, and do not contradict, any axiom.

This definition of "mathematical truth" a priori limits the realm of application of mathematics. Mathematical truth is not at all related to us, human beings, or even to our universe. Thus, the concepts of mathematics are not at all related to the concepts of "good" and "bad", or anything else related to human existence. Mathematics does not claim to be useful. Its usefulness or uselessness has nothing to do with the "truth" perceived and expected by humans.

Based on the above descriptions of mathematics it is clear that a reliability function does not know how reliable it is. Hence, the author started to search for the answer on behalf of all reliability engineers and managers that have been using it for half a century [25]. The objective of this research was to understand of the physical properties that mechanical, electrical, civil, chemical and other systems must have, in order for the system reliability function to represent a statement that was always true, from the point of view of mathematics. For the system reliability function to be true, the following must also be true:

a. One hundred percent quality of components production and installation.

b. Zero percent errors in transportation, storage and installation tasks.

c. One hundred percent independence of failures between constituent components.

d. No maintenance activities whatsoever take place during the stated interval of time.

e. Continuous operation of the systems and all its constituent components (24 hours per day, 7 days per week and 52 weeks per year).

f. First observable undesirable in-service event is a undesirable in-service event of the system (individual undesirable in-service events of B and C are undetectable till both of them experienced undesirable in-service event).

g. Time counts, for all components, from the "birth" of the system.

h. Fixed operational scenario (load, stress, temperature, pressure, etc.) [1,8].

i. System Reliability is independent of:

i. the location in space (GPS or stellar coordinates)

ii. humans (operators, users, maintainers, managers, general public, etc.)

iii. calendar time (seasons do not exist)

Having understood the mathematical truth of the reliability function the author started questioning the physical truth of the reliability function, as perceived in the world of mechanical, electrical, civil, chemical and other types of engineers who are creating physical systems that exist and function in the real and human observable universe.

Physical Truth of Reliability Function

Physical truth is fundamentally different from mathematical truth. Indeed, there are axioms in the physical theory [26]. However, the definition of truth has nothing to do with them. Physics, unlike mathematics, is a systematic study of our universe and its rules. The definition of physical truth is both simple and deep. It centres on the physical experiment and states: "A statement is true if and only if it can be verified in an objective scientific experiment i.e. if the results obtained from the statement fit those of the experiment." [24].

It is necessary to stress that the nature of physical axioms is different from that of mathematical axioms. These axioms are not generated from inward thinking; they are a result of observing surrounding universe and making assumptions about it. For example, the axiom of the homogeneity of time states that: The laws of physics are independent of time. Hence, repeating experiments done a hundred years ago will generate exactly the same results.

Systematic research performed by the author during several decades of the observable physical reality concerning occurrences of undesirable in-service disturbances in the "lives" of functionable systems in aerospace, military, automotive and nuclear power industries has clearly shown that the flowing physical reality determines the reliability performance of systems:

a. Quality of produced components and assembled systems is less than hundred percent satisfactory [1, 22,18,27].

b. Percentage of transportation, storage and installation tasks completed erroneously is greater than zero (clearly manifested through guaranty and warranty claims) [1,25].

c. Evidential interactions between "independent" components (when engine experience an undesirable in-service event the request for transmission, braking, steering and many other components cease to exist) [1,10,14,15,28].

d. Maintenance activities like: inspections, repair, cleaning, etc., have significant impact on the operation of systems and impact their reliability performance [1,27,18,29].

e. Systems and components do not operate continuously (24 hours per day, 7 days per week and 52 weeks per year) [1,27,30].

f. The first observable undesirable in-service event is not necessarily result in an undesirable in-service event of a system (malfunction of components B or C alone, in Figure 1, does not cause a system undesirable in-service event) [1].

g. Components and the parent system have different "times" [1,23,30,31].

h. Variable operational scenarios (load, stress, temperature, pressure, etc.) [1,8,30,32].

i. System Reliability is dependent of:

i. The location in space defined by GPS or stellar coordinates [1,9,11,12,30,33-36].

ii. Humans, (like: users, maintainers, general public) [1,17,18].

iii. The calendar time (geographical seasons exist) [1,8,13,30,33-35].

Having observed the physical truth of the occurrences of undesirable in-service disturbances throughout the life of functionable systems the author started questioning the adequacy of using the reliability function, defined in terms to satisfy mathematical truth, for the prediction of expected reliability performance by the mechanical, electrical, civil, chemical and other types of engineers in design office [1,30].

Summary

The main objective of this paper was to explore the degree of reliability contained in the reliability function currently used to predict the reliability performance of functionable systems. This was achieved by contrasting two different truths, namely:

a. Mathematical truth that defined reliability through reliability function which does not violate any axioms of mathematics.

b. Physical truth that is obtained by systematic studies and analysis of in-service occurrences of undesirable disturbances, many of which do not feature in the currently used reliability function.

The latter truth is based on the laws of science, which denies the existence of parallel universes where the physical laws are either ignored or bent to accommodate administrative or contractual requirements [25]. This paper has fully disclosed the real nature of the former truth. It is imbedded in the well accepted mathematical formulation of system reliability that requires the acceptance of existence of "alternative universe" that is based solely on mathematical truth, while totally ignoring the physical existence of operational, maintenance and support processes which, in themselves, generate undesirable in-service disturbances.

The continuous reliance on the mathematical truth in Reliability Theory stems from neither science nor observation, but from a lack of reliability professionals to systematically evaluate and document consequences in using models and processes that do not accurately reflect the future reality of the functionable systems delivered to the end users. Finally, it is necessary to stress that the current situation where the reliability function follows the mathematical truth rather than physical truth is not the "fault", of the mathematics, as it does not know that reliability professionals even exist! [37,38]

Closing Question to Reliability Professionals

The discrepancies between reliability properties of functionable systems conceived in accordance with mathematical truth and reliability performance observed and documented in accordance to the physical truth have been clearly identified in this paper. The major concerns are the assumptions of independencies of the constituent components and the to6tal luck of considerations of the impact of the natural environment and human actions on the reliability performance of functionable systems throughout their lives.

The closing question for all reliability professionals is, “How can predictions of reliability performance of functionable systems be “reliable” when lifelong physically observable events and associated human rules are totally excluded from the predictions that are based on, what can only be described as “reliability fiction”, rather than reliability function!

Acknowledgement

The author wishes to acknowledge the assistance of thousands of students, at undergraduate and postgraduate level, from the School of Engineering at Exeter University (1984-2001) and MIRCE Akademy (1999-curent) in his continuous quest for the physical truth regarding mechanisms that generate undesirable in-service disturbances, which govern the reliability performance of functionable systems.

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