

# Mathematical and Physical Reality of Reliability

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## ***Abstract***

The accuracy of the mathematical predictions of reliability is fundamental for the system design and life-long failure management processes. Initiated by the personal experience gained by rallying a hand assembled car author has studied the physical properties that a future system must possess, in accordance with the mathematical view of reality defined by reliability function. The results of the study are presented in the first part of the text. These findings are tested through scientific studies of a large number of physically observed failures generated by operation, maintenance and support processes of defence, aerospace and nuclear power systems. The results obtained, presented in the second part of the text, show significant discrepancies between the mathematical reality of reliability based on mathematical theory of probability imbedded in reliability function and the physical reality observed. Thus, this research has exposed the reliability and safety community to the duality of mathematical and physical reality of reliability, as delineated by this chapter. The importance of understanding this duality is essential for the accuracy of reliability predictions, which is the bedrock of reliability and safety engineering.

**Keywords:** Reliability function, mathematical reality of reliability, observed failure events, physical reality of reliability predictions

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Sanjay K. Chaturvedi, Heeralal Gargama and Rajiv N. Rai (eds.) Design and Manufacturing Practices for Performability Engineering, (1–36) © 2025 Scrivener Publishing LLC

## 1.1 Introduction

*“I shall conduct the reader over the road that I have myself travelled, rather a rough and winding road, ‘because otherwise I cannot hope that he will take much interest in the results at end of the journey.’— Albert Einstein<sup>1</sup>*

The main objective of this chapter is to expose the reliability and safety specialist to the journey over the “reliability road” that I have travelled, but it is not a chapter about me; this is a chapter about my discovery of the duality of reliability reality, namely: mathematical and physical. This recognition is essential for the creation of reliability science. The predictions in physics, chemistry, astronomy, thermodynamics and other well-recognized scientific disciplines are based on mathematics but the accuracy of predictions is confirmed by measurable parameters in physical reality. Hence, positioning reliability in the scientific discipline will enable reliability engineering to stand shoulder to shoulder with mechanical, electrical, aerospace and other well-recognized engineering disciplines. For that to happen, the unity between mathematical and physical reality of reliability must be established; and for that to happen, the differences must be identified. Hence, the main objective of this chapter is to clearly present the differences identified by the author.

My long and challenging journey along the reliability road started more than 50 years ago and consisted of the following three stages:

- Experiencing physical reality of reliability.
- Understanding mathematical reality of reliability.
- Studying physical reality of reliability.

Each stage is described briefly in the chapter, as the stepping stone towards the formulation of the final conclusion.

## 1.2 Experiencing Physical Reality of Reliability

My childhood was dominated by a love for cars and everything related to motorsport. For me, a year was the measure of time between two Formula 1 Monaco Grand Prix races. With the passing of the years, my attention

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<sup>1</sup>Proceedings of the Prussian Academy of Sciences, Cosmological Considerations on the General Theory of Relativity, Vol. X, 1917 (p. 142)

gradually drifted towards the Monte Carlo Rally. I found totally irresistible the challenge of driving as fast as possible for hours and days on many different road surfaces, continuously facing numerous challenges, from traffic conditions to system failures, while following the strict time table governed by the rules and regulations. While attending secondary school I became involved with the maintenance of my father's car. In my mind that brought me closer to rallying, where the principal axiom is: "to finish first, first you need to cross the finish line". Hence, from a very early age I learned the importance of reliability regarding the crossing the finish line.

In 1971, when the time came to choose a university subject, I had no dilemma. The Faculty of Mechanical Engineering was the place where I expected to learn how to design reliable cars and how to maintain their reliability in service, thus crossing the finish line, on time, at the end of a rally. However, the first three years were packed with mathematics, thermodynamics, fluid mechanics and similar subjects, none tangible to motorsport. Hence, I decided to change that by taking a hands-on approach to my studies by trying to play an active role in motor sport.

In the spring of 1974 I assembled a car, Zastava 750, from a newly purchased body shell and all other parts acquired from scrap yards. The whole process took place in a neighboring garden during a six-week period of hard, but pleasurable work. The following year I started rallying in that very car. Not having any sponsorship, in addition to the cost of competing, I had to look after the preparation and maintenance of the car, with an almost non-existent student's budget. Hence, the origins of the question that has tormented me for years: which spares to purchase in order to increase chances of crossing the finish line? Clearly having spare fuel, water and oil pump will be beneficial, but I could afford to purchase only one of them. Of course, that was always an option getting all three of them from a scrap yard for a similar amount of money. However, each pump requires different tools for replacement and has different consequences on my quest for crossing the finish line. While continuing solving integrals and differential equations required by my mechanical engineering syllabus, I realized that a mechanical engineering degree would not equip me with the knowledge required to address my challenge. I was seeking for a body of knowledge to assist me to maximize my chances of crossing the finish line, with the resources that my budget allowed. At the same time, I could not get any firm answer from the members of my auto club, as each of them gave me a different answer based on personal opinions.

### 1.2.1 Joining the Rallying Community

1975 was the year when my childhood dreams to be a rally driver were to come true. By early spring I had almost completed the transformation of my “hand-made” to my “rally-ready” car. The reality was, apart from the new body shell and tires, all, but all, other parts of the car were second-hand, with totally unknown past history to me!

In a military scrap yard, I found a big metal toolbox that when opened had three shelves on each side that became fully exposed. Having got a toolbox, I had the biggest problems to solve. It was the selection of spare parts that I intended to take with me to each rally. Of course, the monetary value of spares was important for my budget, but even more the consequences of not having a spare part when needed was the governing criteria. Another decisive criterion for the spare’s selection was the actual time required for changing the part. Bearing in mind that the cumulative delay allowed, during the entire rally was 30 minutes, I felt that there was no point taking the oil pump with me, but choosing between the fuel pump and the water pump, was an extremely difficult, but crucial decision. As a beginner I asked some of the more experienced drivers, within the Akademac Motor Club, about spares and surprisingly each gave me a rather different answer! The question of spares selection bothered me a lot, but at that time, I could not find anybody who had any method for addressing this question “properly”. I also calculated that by now I passed 30 exams within the Faculty of Mechanical Engineering, solved over 300 integrals and differential equations, but not a single one was helpful in this situation. Being an optimist, I was hoping that the remaining year and a half of studying would cast some light on my problem [1].

I was very pleased that my very good friend and student colleague volunteered to be my co-driver. It was a very important part of the preparation for the competition, as co-drivers have a significant impact on the safety and performance of the rally drivers. Even more, it is essential to have a person in the seat next to you whose personality and behavior would have a positive impact on the whole atmosphere in the car during the hours and days of driving on the edge of your physical and mental capabilities.

All the participants of the 1975 Yugoslav Rally Championship were grouped into the following six categories: over 2000 cc, 1600-2000 cc, 1300-1600 cc, 1000-1300 cc, 785-1000 cc and up to 785 cc, which was known as “the national class”. Hence, cars with similar performances were competing directly against each other. Also, that was the order of cars at the start of the rally, which is intended to prevent slower cars affecting the times of the faster cars.

### 1.2.2 Experiencing First Rallying Reality of Reliability

Almost a year after my “hand-made” car became a road legal car; it became a rally car at the start of the XI April Rally, which was a part of the Yugoslav Rally National Championship, together with another 79 teams. The start and finish of the Rally were at the Belgrade Fairground, during the Annual Belgrade International Car Fair. The Rally was driven on the 5<sup>th</sup> and 6<sup>th</sup> April 1975, over the course of 618 km, for which the allocated time was 680 minutes, with four speed trials. As we were allocated the start number 70, we were due to start exactly 70 minutes after the leading car. As four teams failed to come to starting line, we had a starting time of 12:06 hrs. It meant that we were expected to cross the finish line at 23:59, and thus fulfil my lifetime dream!

At 13:56 hrs. we checked in on time at the first Time Control Station (TCS) after completing 99 km in allocating 110 min, after successfully completing the first Speed Trial (ST). 81 km later, including the second ST we checked in on time to the second TCS at 15:21 hrs. The first impressions among us were great, as all was going in accordance to plan, without any reliability worries. Having successfully completed the open road driving session of 100 km we arrived at the third TCS on time.

Precisely on schedule, at 17:11 hrs., we left the TCS heading towards the base of the mountain; the elevation at the top is 1200 meters above sea level. After a few minutes of uneventful driving, we arrived at the start of the 11 km long ST. With helmets on, seat belts fastened, with the pace notes ready we were ready to drive the speed trial on the road closed for public use at that time.

The start official began counting from five to one, and finally raised the green flag and released the KGT. I pressed the throttle as fast and as hard as I could. Simultaneously a huge bang was heard by everyone standing there. I looked at my co-driver who was looking at the pace notes, then I looked at the rev. counter, which was showing that the engine had reached 5600 rev/min, which indicated that the engine was working correctly. I looked at the other instruments available on my dashboard and all were showing normal values. I continued driving as fast as I could, as this speed trial had the highest impact on the final standing at the end of the rally, because it was the longest. Of course, my competitive instincts were stronger than my “car caring” ones and I continued driving fast and climbing up the mountain. It went on for a good 4-5 minutes when the engine suddenly stopped and brought the car to a standstill, in the middle of the road. With help of a few spectators, our car was pushed aside [1].

After opening the engine cover everything became clear. A third of the water-pump pulley was missing without a fan belt on it and there was a huge puddle of cooling liquid at the bottom of engine compartment. We could not understand the connection between the damaged pulley and splashed cooling liquid. The radiator cap was firmly tightened on the top of the radiator, the water pump was dry, and the rubber pipe that takes the cooling liquid to the radiator was in good condition. I opened the radiator and discovered that it was empty, which meant somewhere in the cooling system, something has broken. Then, I put my hand between the bottom of the engine block and the radiator and to my total shock I felt that the connecting hose was totally “shredded”. Clearly, the cooling liquid escaped through these holes. Hence, the failure process started by a part of the pulley breaking off, causing the belt to fall off, and therefore, stopping the operation of the water pump. It completed the cooling liquid to reach a boiling temperature and expand the pressure in the radiator bottom hose to the level it could not contain, ending in explosion.

### 1.2.3 Understanding the First Rallying Reality of Reliability

In summary, a decade long dream of being an active part of the motor-sport community which occupied my youth, finished short of 335 km of crossing the finish line at the first attempt on the 1975 Yugoslav Rally Championship. Although it was an extremely disappointing end of my first rallying attempt, it was not surprising. The reliability of the handmade car from a totally unknown scrap yard acquired used components was a totally unknown entity.

The engine, water pump, and fan belt came from the same donor. On the fan belt pulley, there were traces of white paint, as shown in Figure 1.1. This fact clearly indicated that the car to which it belonged was resprayed, for whatever reason, at least once in the past. The odometer of the six year old donor car showed 68,567 km, but there was no information to confirm that the engine was original to the car.

The radiator and bottom radiator hose came from different scrap yards, which were different from the engine’s scrap yard. Neither of them had shown any visible signs of damage or leakage prior to the start of the rally.

At the start of the speed-trial instant when I pressed the throttle pedal hard, a part of the pulley wheel separated, most likely due to fatigue. Without a grip of the whole 360°, the fan belt fell off and caused the water pump to stop working. This sequence of failure actions was pretty instant and simultaneous, as shown in Table 1.1.



**Figure 1.1** Failed water pump pulley.

**Table 1.1** Time sequence of failure events of the engine during the first rally.

Component	Sequential time [sec]	Cumulative time [sec]
Pulley wheel	0	0
Belt	0	0
Water pump	0	0
Cooling liquid	+ 45 approx.	45 approx.
Rubber hose	+ 120 approx.	165 approx.
Engine	+ 100 approx.	265 approx.

The water pump provides the circulation of a cooling liquid from the radiator through the cooling circuit, into the engine and back to the radiator. The heat that the cooling liquid takes from the engine is transferred to the air at the radiator. However, in my rallying reality with a non-working water pump, the cooling liquid just stayed stationary and the transfer of heat between the engine and the environment ended. Unaware of this entire happening, I continued driving and thus continued generating heat in the engine without any mechanisms to release it into the air.

Consequently, the additional heat generated by the engine was released into the cooling liquid. This additional heat energy started increasing the temperature of the cooling liquid far beyond boiling point. The relentless supply of extra heat generated by the engine working at high revolution regime drastically increased the pressure in the engine cooling system causing the weakest item failure; in this case it was a rubber hose the strength of which could not sustain the stresses generated by an overheated cooling liquid. Hence, the bottom water hose physically disintegrated and finally established the pressure equilibrium with open air. Consequently, the only way for the cooling liquid to proceed was out of the engine *via* the shredded water hose.

It is generally accepted that the piston assembly accounts for a large percentage of the total engine mechanical power loss. Maintaining a proper running skirt profile and skirt-to-bore clearance at the operating temperature is essential for piston friction reduction. Pistons for most car engines are made of an aluminum alloy which has a thermal expansion coefficient 80% higher than that of the cast iron material commonly used for the engine block. Thus, it is essential for the running clearance under engine operating conditions to be maintained. Without the water pump working, shredded water hose and no existent cooling liquid in the engine cooling system, the constantly generated heat from the running engine inevitably reached the operational temperature at which running clearance ceased to exist. Thus, the overheated engine stopped working and caused our car to stop on the middle of the road a few minutes from the start of the ST.

The time dynamics of the sequence of events that ended our journey during my first rally competition is shown in Table 1.1. Although the timing of individual events is approximate, the total sequence and its duration is pretty accurate.

From the above table it is easy to conclude that I, as an enthusiastic novice, caused the total loss of the cooling liquid, shredding of the rubber hose, and seizing of the engine, by continuing driving the car after the “big bang” noise at the start of ST. Although I made no contribution to the failure of the pulley wheel, my decision to continue driving caused failures of other components in the time sequence shown above. The additional and unnecessary failures caused several hours search for spare parts I did not have and much longer repair time. The whole recovery process was by far longer than 30 minutes allowed by rallying regulation, which meant the immediate disqualification from the rally.

### 1.2.4 Summary of Experienced Physical Reliability Reality

In summary my rallying career lasted two years. During that time, I competed in 5 rallies for the Yugoslav National Rally championship, two of which were part of the European Rally champion. We finished two out of five rallies entered and gained one point for the 1976 championship by arriving 6<sup>th</sup> in the national class.

During my two active years of rallying and decades of following world championship, I gained a significant experience regarding the actions and events that determined the chances of crossing the finish line. In the language of 22 years old mechanical engineering student, without any lectures or teaching in reliability, I would summarize the reality of experiential rallying reliability with following words:

- When engine fails, gearbox does not work.
- Tires get punctured by road debris.
- Other road users could damage your car (cars, animals, etc.).
- January Rally in Sweden and in Kenya is very different!
- Second hand parts usually do not last as long as the new ones!
- Incorrectly tightened wheel nuts will not keep a wheel on for a long.
- When a tree is used to stop a car, rather than breaks, lots of other components get immediately “informed”!
- Omitting to install a single washer, could have huge consequences on the system reliability.
- Engine does not work without petrol!
- Strong head wind reduces declared maximum speed.

Having realized all the facts listed above I was keen to understand them and eliminate their reoccurrences during the in-service life of many different engineering systems used by countless numbers of users all over the world. In essence, I finished my rallying career and started the search for the body of knowledge that could help me in my quest.

## 1.3 Mathematical Reality of Reliability

Mathematics is a body of knowledge created by humans, which is based on a set of axioms that are not related to the existing universe. At the same time, mathematics is used in every aspect of human life, from shopping to

space travel, not because it represents an absolute truth, but because it is found to be useful through our experience.

The existing body of knowledge of mathematical probability theory<sup>2</sup> enabled the developed probabilistic measures of reliability, like: failure function, reliability function, expected time to failure, hazard function, mission success and so forth [2]. All of these measures of reliability are uniquely defined by the probability distribution of a random variable, known as the Time To Failure (TTF). However, it is necessary to stress that the concepts of: probability, probability distribution, and random variable exist only in mathematics, not in the real physical world.

### 1.3.1 Mathematical Reality of Reliability of a Component

The most frequently used model of reliability is the reliability function, denoted as  $R(t)$ . It is the probability that a component will operate without failure during a stated interval of time  $[0, t]$ , thus:

$$R(t) = P(TTF > t) = \int_t^{\infty} f(t)dt, t \geq 0 \quad (1.1)$$

where:  $f(t)$  is the probability density function of the random variable TTF.

Once a probability distribution of the TTF is identified, the reliability function and all other reliability measures become known. From the point of view of mathematics, any well-defined probability distribution that satisfies mathematical rules can be used to model the reliability of components.

However, to be practically used, the selected probability distribution function should reflect the expected in-service behavior of the components considered. Hence, designers and producers of components are the most suitable source of information regarding the selection of the relevant probability distributions to model the mechanisms that generate their failures [2].

### 1.3.2 Mathematical Reality of Reliability of a System

A system is a collection of components on which at least one measure of performance is defined. An expression that defines the state of a system as a function of the states of its components is called a system function. Thus,

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<sup>2</sup>The analysis of games of chance by Blaise Pascal, Pierre Fermat, Christian Huygens and Jacques Bernoulli has given birth to the calculus of probabilities, long time viewed as a minor branch of mathematics [5].

the reliability function for a system,  $R_S(t)$ , which consists of several components, is determined by the impact of failure of each component on the reliability performance of a system, which is graphically described by the reliability block diagram (RBD) of a system considered. For a hypothetical system that will experience a failure event when either component A fails, or components B and C fail, the RBD is shown in Figure 1.2.

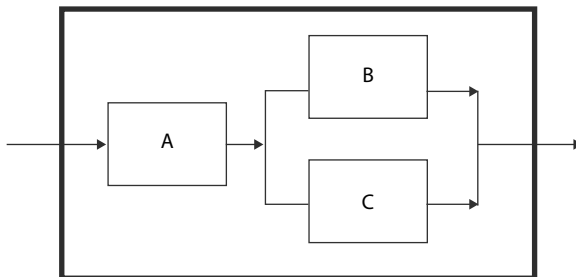
The probability of not experiencing a failure event at the system level, during a given interval of in-service time  $[0, t]$ , is quantified by the reliability function of a system,  $R_S(t)$ , which is defined as:

$$R_S(t) = P(TTF_S > t) = R_A(t) \times [(1 - R_B(t))(1 - R_C(t))], \quad t \geq 0 \tag{1.2}$$

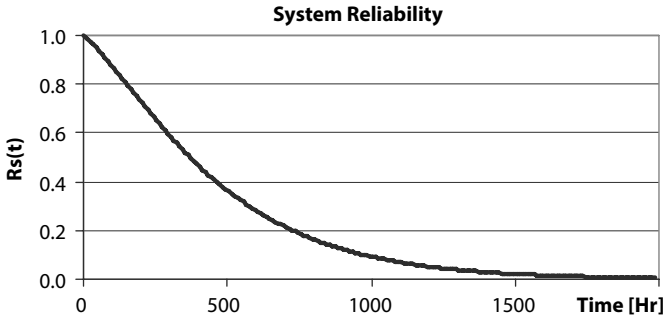
Given that reliability functions of consisting components A, B, and C are known, it is possible to plot the reliability function for a system and calculate the probability of not experiencing a failure event during any interval of future time as failure event during any interval of future time, as shown in Figure 1.3, for a hypothetical system.

The above two figures summarize the essence of the mathematical approach to the reliability modeling process. As its main concern is a prediction of the probability of a given system not experiencing a failure event during a given interval of time it is the governing information for the safety, hazard and similar types of analyses performed at the design stage [3].

In summary, mathematics is telling the reliability and safety specialist that there is a probability function associated with the operation of each physical system. However, mathematics is saying nothing about the probability distribution of that function. From a mathematical point of view, the number of possible probability functions is unlimited. Consequently, the



**Figure 1.2** Reliability block diagram for a hypothetical system.



**Figure 1.3** Reliability function for a hypothetical system shown in Figure 1.2.

final statement of mathematics to reliability and safety modelers is, “I know my limitations” [4].

### 1.3.3 Physical Meanings of Mathematical Reality of Reliability

As a deterministically educated mechanical engineer during the post-graduate studies of reliability engineering I learned that the predictions of the reliability and safety performance of future systems is done by making use of Eq. 1.2, which is governed by reliability functions of consisting components (Eq. 1.1). This approach was universally accepted and promoted by reliability and safety literature since the mid 1950's, which originally were dominated by mathematicians. Consequently, it was an analytical foundation for reliability and safety engineering used in educational and training programs all over the world.

After gaining the first-hand experience from a short rallying career and observing reliability performances of a large number of defense, aerospace and nuclear power systems during the following two decades, I felt the necessity to compare and contrast the mathematical understandings of system reliability and physically observed in-service reliability performance. The main results of this personal quest for clarifying the mathematical understanding of reliability, represented by the reliability function, is briefly summarized below.

#### 1.3.3.1 *Mathematical Reality: Probability of Design and Production Error of Components and Systems is Equal to Zero*

The integral that defines reliability of components (Eq. 1.1) is defined by values of time greater or equal to zero, which means that no reliability and safety relevant events can take a place before the beginning of the

operation. Consequently, all theoretical probability distributions used to define component reliability have a range  $[0, \infty]$ . Knezevic [2], warned reliability modelers that a normal probability distribution, which is defined between minus and plus infinity, should be used in reliability predictions only when the expected value is a minimum three times greater than the standard deviation. This means that the probability of the left tail of the distribution could be ignored, for the modelling purposes.

### *1.3.3.2 Mathematical Reality: Probability of Transportation, Storage and Installation Induced Failures is Equal to Zero*

As a system consists of components, then the system reliability function must have the same mathematical properties as described in Section 3.3.1 for a component reliability function. Consequently, all reliability considerations of a system, as far as mathematics is concerned, start at the “birth” of systems, as  $R(0) = 1$ .

### *1.3.3.3 Mathematical Reality: Probability of Component Dependencies Within a System in Equal to Zero*

The fact that the contribution, the reliability of components connected in series to the system reliability is equal to the product of their individual reliability is valid only if there is no interaction between them, whatsoever. According to mathematics, individual components exist in their own rights, like each one is the only one. This practically means that no failure of any component can impact the reliability performance of any other within a system.

### *1.3.3.4 Mathematical Reality: Probability of Maintenance Induced Failures (Inspections, Repair, Diagnostics, Cleaning, Etc.) is Equal to Zero*

Mathematical expressions for failure and reliability functions (Eqs. 1.1 and 1.2) of components within a system are continuous integrals within a given interval of time  $[0, t]$  exclusively related to the TTF. Hence, interruptions for inspections, testing, condition monitoring and similar maintenance actions related to any of consisting components are “non-existent” as far as mathematics is concerned. Thus, no maintenance actions are incorporated into failure or reliability functions, as both are covering the length of operational time to failure.

*1.3.3.5 Mathematical Reality: Probability of Discontinuous Operation of the System and Components is Equal to Zero*

As expressions for reliability of any component and system are defined by the continuous random variable, namely Time To Failure, TTF, no interruptions in continuity of time are “allowed”. In other words, shifts, weekends, “Queen Jubilees”, national days, religiously significant days, are totally non-existent, from the point of view of Reliability Theory.

*1.3.3.6 Mathematical Reality: Probability of Variable Operational Scenario (Load, Stress, Temperature, Pressure, Etc.) Impacting Reliability is Equal to Zero*

There are systems whose operational scenario are determined by the seasonal, daily, or even hourly changing patterns, each of which generates different stresses and loads on the systems, and consequently impact the reliability and safety. However, probability distribution functions available in mathematics to be used for modeling TTF are unable to deal with the operational variability of physical reality.

*1.3.3.7 Mathematical Reality: Probability of a Location in Space (GPS or Stellar Co-Ordinates) Impacting Reliability is Equal to Zero*

In all probability distributions where the TTF is used as a relevant random variable for the reliability predictions, the mathematically defined probability density function is totally divorced from the physical location of a system. Hence, a system defined by identical reliability function, will have identical reliability performance irrespective of the location of a system in the geographical or astronomical space. The reason for these is very simple; no mathematical axiom is related to physical reality, in any shape or form.

*1.3.3.8 Mathematical Reality: Probability of a Human Actions Impacting Reliability is Equal to Zero*

Although trains, cars, bicycles, buses, lorries and other means of transport are driven by humans, not a single block in the reliability block diagram is related to them. Hence, human actions have no impact on the reliability function.

### 1.3.3.9 *Mathematical Reality: Probability of Calendar Time (Seasons Do Not Exist) Impacting Reliability is Equal to Zero*

Mathematical models based on the reliability function are totally immune to calendar time, which reflects seasonal variability, as the calendar time, represented by mathematical models clearly exhibits the continuation of time, which does not differentiate where on the time axis the interval is located.

### 1.3.4 **Concluding Remarks Regarding Mathematical Reality of Reliability Function**

All of the above factual “discoveries” are not weaknesses of the probability theory, at all. They are just clarified mathematical meanings of the physical reality of the system reliability. According to the axioms of probability<sup>3</sup> any probability distribution, defined by the probability density function whose area under curve is equal to 1, between zero and infinity is perfectly suitable to be used in the expression for failure and reliability functions. Mathematics has neither intention nor ability to decide what is a physical reality of human created and managed systems. The above-deduced “realities” of the reliability measures of systems are just a clear statement of the mathematical truth that says, “In my reality my predictions are correct.”

From the point of view of the probability theory any repeated experiment that provides different outcomes under identical conditions is a probabilistic experiment, irrespective of which mechanisms generate that behavior. Hence, the probability theory is a mathematical scheme that is totally unconcerned with the physical causes and mechanisms that generate failure events in the life of humans, created and operated systems. However, it is the only body of knowledge that enables predictions of the occurrences of failure events throughout the life of systems used daily by humans to be made.

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<sup>3</sup>Kolmogorov, A.N., Foundations of the Theory of Probability, Chelsea Publishing Company, USA, 1950.

## 1.4 Studying Physical Reality of Reliability

Physical reality is related to the natural world and it is studied by scientists. However, it is fundamentally different from the mathematical reality. Although there are axioms in the scientific theory, but unlike mathematical axioms, they are related to the behavior of the universe and its laws, which are based on the physical experiments<sup>4</sup>. For example, one of the fundamental axioms is the axiom of causality, which states that, “In our universe the cause always precedes the result”. This axiom exists and is believed to be true only because no one has ever demonstrated in an experiment that it does not hold [4].

### 1.4.1 Mathematical Reality: Probability of Design and Production Error of Components and Systems is Equal to Zero

To understand the physical reality of reliability the MIRCE Academy has systematically studied in-service behavior of defense, aerospace and nuclear power industries, which are an equivalent to scientific experiments performed in laboratories. For that purpose, the MIRCE Academy Functionability Archive<sup>5</sup> was created in 2013, under the author’s directorship.

The staff and students of the Academy analyzed the natural or human actions to understand the mechanisms that governed them. So far, the Archive has collected around 500 “real life experiments” that shine a light to the physical reality of reliability, from publicly available sources of information.

To illustrate the types, causes, and mechanisms of reliability and safety events that were recorded and studied during last three years at the MIRCE Academy, are listed below.

### 1.4.2 Observed Physical Reality of Reliability in 2020 – MIRCE Academy Functionability Archive

- 7 January 2020: A380 program moves into operational support - Aftermarket Phase

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<sup>4</sup>According to Dubi, “A statement is true if and only if it can be verified in an objective scientific experiment” [4].

<sup>5</sup><http://www.mirceakademy.com/news/2/15/MIRCE-Functionability-Actions/>

- 8 January 2020: Ukraine International Airlines B737 shot down at Teheran airport
- 13 January 2020: Piston seals linked to Pratt A320neo engine failures
- 19 January 2020: High-Altitude abort test completed by SpaceX Crew Dragon
- 20 January 2020: Grounding cost for Boeing 737 MAX
- 25 January 2020: European Space walking record
- 26 January 2020: Boeing 777X starts flight test campaign
- 19 February 2020: Boeing finds debris in grounded 737 MAX fuel tanks
- 20 February 2020: XMM-Newton reveals giant flare from a tiny star
- 25 February 2020: B737 MAXs to get nacelle panel work before service return
- 4 March 2020: Northrop Grumman is DARPA's commercial partner for servicing satellite
- 20 March 2020: UK declared F-35 operational despite availability, infrastructure, logistics and security issues
- 7 April 2020: To minimize COVID-19 exposure the U.S. Space Force delays GPS 3 launch
- 10 April 2020: Rolls Royce scrambles to adjust to Corona virus crisis
- 30 April 2020: Rain triggers volcanic eruption
- 20 May 2020: A380 retirements brought forward by Air France
- 22 May 2020: Flight accident in Karachi by Pakistan International Airlines
- 31 May 2020: SpaceX delivers astronauts to ISS, for the first time
- 2 June 2020: B777 inaccurate fuel-quantity systems targeted by FAA rule
- 2 June 2020: Additional inspections required for fuel and fuel tanks in parked aircraft
- 9 June 2020: Hypersonic test mishap to be investigated by U.S. Air Force
- 10 June 2020: Correct cleaning procedures for COVID-19 causes problems to airlines
- 14 June 2020: All three flight computers failed on landing on A330

- 16 June 2020: Boeing 777 autothrottle wiring repair recommended by FAA
- 5 July 2020: Rocket Lab lost Electron rocket 4 min after lift-off
- 6 July 2020: Windscreen cracks cause emergency landing by B737-800
- 6 July 2020: EASA mandate targets Trent 1000 low-pressure turbine disc issue
- 8 July 2020: Weather causes SpaceX delays Starlink launch
- 10 July 2020: 80% reduction in Rolls-Royce's engine flying hours due to COVID-19
- 15 July 2020: Air France retired its remaining A380
- 22 July 2020: Boeing to service Etihad's 787 fleet
- 23 July 2020: The shifting sands of wide body storage due to COVID-19
- 27 July 2020: Regulators order inspections after downtime is linked to B737 engine incidents
- 30 July 2020: Cathay Pacific moving 60 aircraft to storage
- 4 August 2020: Wiring fixes require before B737 MAX can return
- 12 August 2020: Rolls-Royce detected Trent XWB high-time wear issue
- 31 August 2020: Troubled F-35 autonomic logistics system to be replaced
- 2 September 2020: Boeing identifies two production-related structural issues in multiple 787s
- 23 September 2020: The final Airbus A380 has been assembled
- 2 October 2020: SpaceX aborts launch of advanced GPS satellite for the US Space Force
- 5 October 2020: Metal fatigue caused Airbus A380 engine blow-out
- 7 October 2020: Tug damaged Virgin Atlantic A350 at Heathrow incident
- 8 October 2020: Rolls-Royce bolsters SelectCare Services for Trent 700 engines
- 9 October 2020: Could hackers breach aviation safety?
- 10 October 2020: SpaceX's next astronaut launch for NASA delayed until November
- 10 October 2020: Airbus Delivers the 10,000th A320 family aircraft

- 12 October 2020: A380 Engine failure could prompt new inspections
- 16 October 2020: Potential impact of the Icelandic Grimsvotn volcanic eruption on aviation
- 20 October 2020: Iran Air B747-200 diverts to Tehran with cargo of sheep
- 21 October 2020: COVID-19 causes problems in maintenance planning for SAS
- 23 October 2020: Boeing working to correct B747 flight computer reset issue
- 23 October 2020: Wayward stairs punctured wing on SWISS B777-300
- 28 October 2020: Testia upgrades Smart Inspection Toolkit
- 2 November 2020: Air India receives 5th Hong Kong ban
- 2 November 2020: 30-minute flight put in 4-hour hold
- 4 November 2020: Multiple hydraulic failures strike American Airlines A320
- 11 November 2020: Boarding issues at International Space Station
- 13 November 2020: Antonov An-124 suffers uncontained engine failure and landing gear snaps
- 16 November 2020: Alaska Airlines Boeing 737 hits and kills brown bear while landing
- 17 November 2020: Cat prints found inside El Al B787 in Hong Kong
- 18 November 2020: FAA approves B737 MAX changes
- 1 December 2020: Blocked fuel pump led to Boeing 787 engine shutdown
- 1 December 2020: Bees washed off A320 by a fire engine
- 10 December 2020: To avoid bathroom use Chinese cabin crew advised to wear nappies
- 10 December 2020: Explosion of a SpaceX Mars rocket prototype
- 11 December 2020: Fish removal from Brisbane airport drainage system by Sea world
- 12 December 2020: The United States Federal Aviation Administration (FAA) has authorized pilots and air traffic controllers to receive the COVID-19 vaccine
- 18 December 2020: Nepalese Airline carries passengers to the wrong destination

- 27 December 2020: Windscreen cracks on B787 caused a 9-hour flight to nowhere
- 28 December 2020: Door open indication caused Rossiya Airlines A319 to return to airport

### **1.4.3 Observed Physical Reality of Reliability in 2021 – MIRCE Akademy Functionability Archive**

- 2 January 2021: Tug catches fire preparing to push Lufthansa 747 in Buenos Aires
- 8 January 2021: 737 MAX fraud probe settlement costs Boeing \$2.5 Billion
- 11 January 2021: Bad weather on Earth delays SpaceX Dragon's return from space station
- 12 January 2021: Singapore Airlines asks crew to wear tracking devices on layovers
- 17 January 2021: Virgin Orbit conducts second launch demo flight using B747
- 20 January 2021: West Atlantic cargo B737 damaged landing in Exeter
- 23 January 2021: Windscreen fire causes Saab 340 to land in Anchorage
- 25 January 2021: Delta bird strike leads to emergency landing
- 1 February 2021: Two KC-46 deficiencies fixed by Boeing
- 1 February 2022: After 4 months in maintenance NASA's SOFIA 747 returns to the sky
- 8 February 2021: C919 goes to Canada for cold weather tests
- 13 February 2021: Main cargo door opened after take-off and DHL B757 returns to Leipzig
- 15 February 2021: SpaceX lost a rocket in the ocean
- 20 February 2021: Fist fight onboard of Donghai Airlines flight
- 21 February 2021: Engine failure forced United Airlines B777 to return to Denver international airport
- 22 February 2021: United engine failure caused Boeing to ground some B777s
- 22 February 2021: Suspected fuel leak forces Emirates B777 to divert
- 28 February 2021: Bird strike causes KLM B777 six-hour flight to nowhere

- 28 February 2021: SpaceX aborts launch of Falcon 9 rocket carrying Starlink satellites
- 3 March 2021: SpaceX's SN10 Starship prototype explodes 8 minutes after landing
- 4 March 2021: Satellite based condition monitoring of gas pipelines' leaks
- 6 March 2021: Baltic Air A320 lands with a nose gear rotated 90 degrees
- 8 March 2021: Lightning strike impacted Sao Paulo runway
- 11 March 2021: 2.9-ton of space junk jettison from International Space Station
- 15 March 2021: Flight attendant injured on American Airlines B777 Flight
- 16 March 2021: Laser attack forces Virgin Atlantic B787 Dreamliner Emergency landing
- 18 March 2021: Front landing gear Failure on Viva A320
- 20 March 2021: Volga-Dnepr flies IL-76s Successfully to Antarctica
- 20 March 2021: Volcanic eruption disrupted Iceland Air Travel
- 21 March 2021: Gear collapses on Trigana Air B737-400 in Indonesia
- 22 March 2021: First fully commercial mission of Russian Soyuz rocket
- 24 March 2021: Tire damage departing on B777 while departing Doha
- 24 March 2021: SpaceX launches 60 new Starlink Internet satellites and nails rocket landing at sea
- 10 April 2021: Electrical flaw grounds selected 737 MAX jets
- 14 April 2021: Failure of flight control software postpones the first flight of NASA's Mars helicopter Ingenuity
- 19 April 2021: The threat of decompression panels disengaging on B787 checks registered
- 20 April 2021: Suspected pilot's stroke prompts ANA Boeing 787 diversion
- 21 April 2021: Major damage of SriLankan Airlines A320neo in ground vehicle collision
- 23 April 2021: Jet bridge damaged brand-new KLM Boeing 777 during pushback
- 27 April 2021: Weather delayed NASA, SpaceX return to Earth for Crew-1 astronauts

- 30 April 2021: Bad weather delays SpaceX Crew-1 astronauts' return to Earth
- 3 May 2021: Ingenuity helicopter fails to take off with clock ticking to complete research goals
- 7 May 2021: FAA draft mandate targets Boeing 787 shimmying issue
- 8 May 2021: Huge Chinese rocket booster falls to Earth over Arabian Peninsula
- 11 May 2021: Virgin Galactic return to flight faces new delay
- 12 May 2021: Antonov AN-124 overran runway as Sao Paulo
- 27 May 2021: Bat in business class forces Air India Newark flight to return to Delhi
- 2 June 2021: Seven-hour spacewalk of the decommission old ISS docking module
- 2 June 2021: Space station robotic arm hit by orbital debris in 'lucky strike'
- 13 June 2021: 1980s Computer problem shuts down Hubble telescope
- 18 June 2021: Nose gear collapsed on British Airways B787-8
- 24 June 2021: Pitot tube warning for aircraft returning to service by EASA
- 25 June 2021: Passenger jumped out of taxiing United Express plane
- 28 June 2021: Backup computer of Hubble space telescope experiencing the same error
- 28 June 2021: SpaceX rocket explodes during cargo launch to ISS
- 1 July 2021: Ethiopian Airlines 787 exorcised by Voodoo priest on Togo layover
- 7 July 2021: Tropical storm Elsa delays SpaceX Dragon cargo ship's return to Earth
- 11 July 2021: Wreckage of Boeing 737-200 found in the Pacific Ocean
- 13 July 2021: Hail damages Emirates Boeing 777 on departure from Milan
- 14 July 2021: What caused the British Airways B787 gear collapse
- 20 July 2021: Cabin pressure switches to be inspected more frequently on B737
- 21 July 2021: After engine fire UPS B747-8 returns to Hong Kong

- 25 July 2021: Russia replaces docking port with new space station module
- 28 July 2021: Young kestrels found in Airbus A320 APU in Wales
- 30 July 2021: Failures of lavatory fire extinguishing bottles in a COVID-19 stored aircraft
- 6 August 2021: First attempt to collect Mars samples with Perseverance rover comes up empty
- 9 August 2021: Stowaway pigeon delays United flight to Athens
- 9 August 2021: Under specific scenario B737 MAX Cargo Capacity Restriction
- 10 August 2021: Accelerated degradation of A350 fuselage surface
- 12 August 2021: Catastrophic failure during launch of Indian Earth observation satellite
- 16 August 2021: A Malaysian satellite has died in space and will meet a cold grave
- 23 August 2021: Cell phone fire causes evacuation of Alaska Airlines B737
- 24 August 2021: Pinched nerve prevents NASA astronaut from spacewalk
- 27 August 2021: Pilot dies after in-flight medical emergency of Biman Bangladesh Airlines
- 2 September 2021: Major anomaly causes explosion of Firefly Aerospace's first Alpha rocket
- 9 September 2021: Fuselage cracks on Airbus A380 requires reinforcement by EASA
- 14 September 2021: Last Airbus A380 retires from Lufthansa
- 3 October 2021: Bird strike causes engine fire of A320neo during the take off
- 11 October 2021: Solar storm hits Earth, bringing northern lights to New York
- 18 October 2021: Gamma- ray nearly kill European space telescope
- 19 October 2021: MD87 overshoots runway and bursts into flames
- 10 November 2021: ISS dodged Chinese space junk before SpaceX Crew-3 astronaut launch
- 16 December 2021: Faulty cable causes launch delay of James Webb Space Telescope

- 16 December 2021: Aeroflot A350 hits de-icing truck taxiing in Moscow
- 21 December 2021: Boeing and Airbus warn that deployment of new 5G wireless services could harm aviation safety urge delay in roll out
- 24 December 2021: Paint is flaking on air New Zealand's B787 wings
- 27 December 2021: Headwinds force domestic AA 737 flight to divert for fuel
- 28 December 2021: Catering truck drives into LOT 737 MAX winglet at Heathrow.

#### **1.4.4 Observed Physical Reality of Reliability in 2022 – MIRCE Academy Functionability Archive**

- 4 January 2022: Fire onboard diverts Ryan Air B7374
- January 2022: Tail strike damaged British Airways A350 at Heathrow
- 5 January 2022: Drone-Based aircraft inspections at Korean Air
- 9 January 2022: FAA details 50 airports that will have 5G buffer zones
- 18 January 2022: Most B777 flights to US cancelled due to 5G roll-out
- 19 January 2022: Ash from Tonga volcano eruption reaches record altitude
- 27 January 2022: Door ripped of British Airways B777 in Cape Town
- 28 January 2022: B747F damaged after colliding with baggage cart
- 2 February 2022: Service return mandates for Pratt & Whitney powered B777s
- 4 February 2022: Landing gear of Sun Country B737 collapse on landing
- 7 February 2022: Geomagnetic storm destroys 40 SpaceX Starlink satellites
- 8 February 2022: Curiosity rover's wheels severally damaged by rugged Mars
- 10 February 2022: Astra rocket suffers catastrophic failure in 1st Florida launch

- 18 February 2022: Fuel system part linked to UPS 747-8F incident
- 22 March 2022: Boeing 777 fuel systems modifications requested by FAA
- 23 March 2022: Spacewalking astronauts completed maintenance tasks on ISS
- 23 March 2022: Material defect prompts PW1100G-JM inspection mandate
- 29 March 2022: A320 Lands with nose gear rotated by 90 degrees
- 6 April 2022: Malaysia Airlines 737 drops 7000 feet in seconds
- 7 April 2022: Crash landing of DHL B757 in San Jose
- 14 April 2022: Corrosion from inactivity flagged on Pratt-powered 777 engine parts
- 21 April 2022: Thrust reverser deploys during go-around on TAP A320
- 3 May 2022: Mumbai airport will close for 6 hours to allow monsoon preparation
- 7 May 2022: Software bug prompts EASA emergency directive for Airbus A350
- 12 May 2022: Tibet airlines A319 caught fire during takeoff in China
- 13 May 2022: Third failure in a row for iSpace's hyperbola 1 rocket
- 23 May 2022: Dozens of flights diverted due to bad weather at Delhi airport
- 25 May 2022: Ransom-ware attack impacting SpiceJet operations
- 6 June 2022: Faulty simulator training, 90 SpiceJet pilots banned from flying B737 MAX
- 8 June 2022: NASA project gathers data on climate influencing thunderstorms
- 10 June 2022: Micrometeoroid hits James Webb Space telescope just months into flight
- 12 June 2022: McDonnell Douglas MD82 catches fire after landing at Miami Airport
- 13 June 2022: Astra rocket suffers second failure
- 16 June 2022: ISS dodges orbital debris from Russian anti-satellite test

- 17 June 2022: ITA Airways Airbus A330 hits Air France B777 and takes off
- 19 June 2022: SpiceJet Boeing 737 engine catches fire after bird strike
- 24 June 2022: Wild solar weather is causing satellites to plummet from orbit
- 26 June 2022: US Congress eyes another Boeing audit after multiple B737 MAX incidents
- 28 June 2022: Nose gear trouble landing in Hamburg for SAS ATR-72
- 1 July 2022: Large hole in fairing on Emirates Airbus A380 when landing in Brisbane
- 5 July 2022: NASA's tiny CAPSTONE probe goes silent on its way to the moon
- 7 July 2022: Minotaur rocket explodes 11 sec after launching on test mission for US military
- 7 July 2022: Trash bag jettisoned from ISS in waste-management first
- 10 July 2022: Landing gear catches fire in Atlanta with passengers on board of Spirit Airlines
- 11 July 2022: Repair issue prompts 787 fire shutoff switch swap order by FAA
- 17 July 2022: International carriers made 3 emergency landings on Indian airports within 48 Hours
- 17 July 2022: Micrometeoroid strikes damaged James Webb space telescope
- 18 July 2022: Storm damage grounded flying telescope SOFIA
- 18 July 2022: Satellite dodges space debris as it scrambles against space weather
- 21 July 2022: SpaceX aborts launch of Falcon 9 rocket 46 seconds before lift-off with 46 Starlink satellites
- 26 July 2022: Engine fire causes aborted takeoff on A321
- 29 July 2022: FAA approves Boeing 787 Inspection, delivery restart plan
- 29 July 2022: F-35s Join grounded as Martin Baker ejection seat could be faulty
- 31 July 2022: Pressurization Problem causes Airbus A330 Returns To Heathrow
- 2 August 2022: B737 lands in Amsterdam with open cargo door

- 2 August 2022: Belly landing of F16y shows landing gear issues persisting
- 6 August 2022: Failed sensor prevents India to put satellites in right orbit in debut launch
- 6 August 2022: Lightning strikes 2 IndiGo engineers during ATR check
- 15 August 2022: Pilots miss landing because they were asleep
- 22 August 2022: Smoke in cockpit of B747-8 declares emergency and diverts to Boston
- 23 August 2022: A pilot reportedly fainted on a Jet2 flight to Turkey
- 25 August 2022: Typhoon expected to disrupt Hong Kong flights
- 29 August 2022: Technical issues Nixes first SLS launch attempt
- 3 September 2022: Airbus A320 hits motorcycle on landing in Guinea
- 7 September 2022: Astronauts' blood shows signs of DNA mutations due to spaceflight
- 7 September 2022: Leaky seal on Artemis 1 to be replaced at the launch pad
- 12 September 2022: Launch failure grounded Blue Origin's New Sheppard rocket
- 21 September 2022: Falling sparks and debris forced United Airlines B777 return
- 1 October 2022: Firefly declares Alpha rocket launch success but satellites fall back to Earth
- 6 October 2022: Last minute abort of SpaceX Falcon 9 rocket double-satellite launch
- 8 October 2022: Scottish rocket start-up Skyrora fails on 1st space launch attempt
- 11 October 2022: Japan's epsilon rocket fails during launch of tech-demonstrating satellite
- 23 October 2022: Korean Air A330 overshot the runway
- 25 October 2022: Software upgrade on A220 engine mandated by FAA
- 28 October 2022: Engine failure on IndiGo Airbus A320 caused rejects takeoff
- 30 October 2022: Sub-two second pit stop for McLaren F1 Team

- 7 November 2022: Subtropical storm Nicole delays SpaceX launch to Saturday
- 7 November 2022: Cygnus cargo ship is trying to reach ISS with only 1 solar array deployed
- 8 November 2022: DARPA's robot could start servicing satellites in 2025
- 8 November 2022: A340 Diverts to Boston twice following engine issues
- 9 November 2022: Inscribing serial numbers during inspections of propellers caused grounding of 116 C-130 H aircraft
- 10 November 2022: Tropical storm Nicole batters Florida as NASA's Artemis 1 moon rocket rides out storm
- 11 November 2022: China's long March 6a launches successfully but upper stage breaks up
- 14 November 2022: Heavy Storm Damage A330 and A320 in Flight over Jeddah
- 6 December 2022: Final B747 rolls off the production line today
- 8 December 2022: First C919 delivered to China Eastern
- 13 December 2022: Airbus A330Neo damaged before delivery
- 14 December 2022: Soyuz spacecraft suffers 'fairly substantial' leak at space station, cancels spacewalk by Russian cosmonauts
- 14 December 2022: China's launch of world's 1st methane-fueled orbital rocket fails
- 15 December 2022: Technical fault identified After F-35B crash
- 19 December 2022: IT failure causes delay chaos for British Airways passengers
- 19 December 2022: Several serious injuries reported on turbulence-struck Hawaiian Airlines A330
- 21 December 2022: Europe's Vega C rocket fails during second stage
- 21 December 2022: Flight VV22 failure: Arianespace and ESA appoint an independent inquiry commission
- 21 December 2022: Martian dust causes NASA to retire InSight Mars Lander

## 1.5 Closing Remarks Regarding Observed Physical Reality of Reliability

The above presented list of physically observed and documented facts seriously raised the question of the credibility of the reliability predictions provided through the reliability function (Eq. 1.2). Even for the simplest possible system shown in Figure 1.1, the system reliability function is unable to consider the situation where either of the components, B or C, fail and get recovered before the failure of the other. Eq. 1.2 is only applicable to the situation where the system operates until both of them fail.

Even further, what is the reliability function for the failed components that are replaced by their original manufacturer in comparison to those that are replaced by second-hand parts?

All research and analysis of the physically observed failures during the in-service operation in physical reality led the author to the following conclusions [6]:

- Probability of design and production error of components and systems is greater than zero;
- Probability of transportation, storage and installation induced failures is greater than zero;
- Probability of component dependencies within a system is greater than zero;
- Probability of maintenance induced failures (inspections, repair, diagnostics, cleaning, etc.) is greater than zero;
- Probability of discontinuous operation of the system and components is greater than zero;
- Probability of variable operational scenario (load, stress, temperature, pressure, etc.) impacting reliability is greater than zero;
- Probability of a location in space (GPS or stellar coordinates) impacting reliability is greater than zero;
- Probability of human actions impacting reliability is greater than zero;
- Probability of calendar time impacting reliability is greater than zero (seasons do exist).

Full justification for some of the above conclusions has been described and given in the chapters published by author given in the Appendix 1.1.

### 1.5.1 Comparison Between Mathematical and Physical Reality of Reliability

Numerous scientific laws have shown how predictions based on mathematical reality have been confirmed by the results obtained in physical reality. For example, Maxwell laws had shown how predictable and reliable are mathematical relationships between the properties of a gas, pressure, volume and temperature, could be derived from and unknown motions of countless molecules jiggling frantically with thermal energy. In other words, thermodynamics is a science of heat flow, which united large-scale properties of matter like pressure and temperature by applying statistical mechanics on microscopic scale of molecules and atoms.

Based on the information provided thus far, it is possible to summarize that there are significant differences between a mathematical reality of reliability and the observed physical reality of reliability. The major points of the differences between them are presented in the Table 1.2.

Consequently, as observed physical reality cannot be changed to fit mathematical reality of reliability, the only way forward, according to the author, is to adapt existing calculus of probability. Unquestionably, the physical reality of reliability is of probabilistic nature, but it is more complex than the probabilistic theory used to calculate probabilities of experiments like, throwing a dice or turning a roulette wheel [5].

## 1.6 Closing Questions

The accuracy of the mathematical predictions of reliability is fundamental for the system design and life-long failure management processes. Hence, the main objective of this text was to expose the reliability and safety community to the mathematical and physical realities of the reliability function, based on the life-long research conducted by the author.

Initiated by experience gained by rallying a hand assembled car, the author has studied the physical properties that a system must possess, in accordance to the mathematical view of reality defined by reliability function. The results of the study are presented in the first part of the text.

The understood findings of the mathematical reality are tested through scientific studies of a large number of physically observed failures generated by operation, maintenance and support processes within the defense, aerospace and nuclear power systems. The results obtained, presented in the second part of the text, show significant discrepancies between the

**Table 1.2** Comparison between mathematical and physical reality of reliability.

<b>Mathematical reality</b>	<b>Physical reality</b>
<ul style="list-style-type: none"> <li>• Probability of design and production error of components and systems is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of design and production error of components and systems is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of transportation, storage and installation induced failures is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of transportation, storage and installation induced failures is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of component dependencies within a system is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of component dependencies within a system is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of maintenance induced failures (inspections, repair, diagnostics, cleaning, etc.) is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of maintenance induced failures (inspections, repair, diagnostics, cleaning, etc.) is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of discontinuous operation of the system and components is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of discontinuous operation of the system and components is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of variable operational scenario (load, stress, temperature, pressure, etc.) impacting reliability is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of variable operational scenario (load, stress, temperature, pressure, etc.) impacting reliability is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of variable operational scenario (load, stress, temperature, pressure, etc.) impacting reliability is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of variable operational scenario (load, stress, temperature, pressure, etc.) impacting reliability is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of a location in space (GPS or stellar co-ordinates) impacting reliability is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of a location in space (GPS or stellar co-ordinates) impacting reliability is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of human actions impacting reliability is equal to zero</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of human actions impacting reliability is greater than zero</li> </ul>
<ul style="list-style-type: none"> <li>• Probability of calendar time impacting reliability is equal to zero (seasons do not exist).</li> </ul>	<ul style="list-style-type: none"> <li>• Probability of calendar time impacting reliability is greater than zero (seasons do exist)</li> </ul>

mathematical reality of reliability based on mathematical theory of probability imbedded in reliability function and the physical reality observed.

Thus, this research has exposed the reliability and safety community to the duality of mathematical and physical reality of reliability. The importance of understanding this duality is essential for the accuracy of reliability predictions, which are the bedrock of reliability and safety engineering.

Finally, as the observed physical reality cannot be changed to fit mathematical reality of reliability, their reconciliation requires mathematical actions. Unquestionably, the physical reality of reliability is of probabilistic nature, but it is more complex that the mathematical probability theory created to calculate probabilities of experiments like, throwing a dice or turning a roulette wheel. Consequently, the only way forward, according to the author, is for the existing calculus of probability to evolve and thus eliminate the reliability duality exposed by this chapter [7].

## 1.7 Personal Message from the Author

I sincerely hope that this chapter will be beneficial to the reliability community to see the clear distinctions between the mathematical and physical realities of the reliability function with the objective to focus their research on enhancing the existing mathematical methods for predicting system reliability in order to increase the probability of the “Crossing the Finish Line”. It was the main objective of my short rallying career, but also the main focus of nearly half a century of my, much focused, scientific research. However, it has direct applications on all human endeavors taken to satisfy perceived needs, as each of them has an equivalent of my “finish line” in physical reality.

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## Appendix 1.1

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