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Mirce Functionability Equation

Dr Jezdimir Knezevic
MIRCE Akademy, Woodbury Park, Exeter, EX5 1JJ, UK

Abstract
Scientific principles and concepts expressed through the laws, equations and formulas are the bedrock for the prediction of the deign-in functionality performance of any engineering creation. However, there is no equivalent when the in-service functionability performance predictions have to be made. Hence, Mirce Mechanics has been created at the MIRCE Akademy to fulfil the roll. The main purpose of this paper is to present the development and application of Mirce Functionability Equation which is the bedrock for the prediction of the functionability performance of maintainable systems.

I. The Concept of Functionality

According to Einstein ***"****Everything that the human race has done and thought is concerned with the satisfaction of felt needs*".

Human needs for transporting, communicating, defending, entertaining and many other functions are satisfied by ships, airplanes, tractors, computers, radios and other systems. As they are functioning in accordance to the laws of science, which are independent of time, place and human impact, their design-in performance, like speed, acceleration, power, fuel consumption and many others, are accurately predictable. [1]

II. The Science of Functionality

The theoretical foundations of designing systems are laws of science that describe observable natural phenomena, known to humans so far. Among them laws of motion are the most significant from the life cycle engineering and management point of view, in respect to functionality of a system. Some of them are very briefly addressed in this paper as the scientific foundation for the development of the laws of the motion of functionability. Hence:

Newton's laws of motion are three physical laws that form the basis for classical mechanics. These laws describe the relationship between the forces acting on a body and the motion of that body. They were first compiled by Sir Isaac Newton in his work *Philosophiæ Naturalis Principia Mathematica*, first published on July 5, 1687.Newton used them to explain and investigate the motion of many physical objects and systems, from the "apple" to planets.

Kepler's laws of planetary motion are three astronomical laws that describe the motion of planets around the Sun. From them it is possible to accurately predict either what the position of the planet is at a given time, or the time when the planet is in a given position.

Maxwell's equations are a set of four partial differential equations that relate the electric and magnetic fields to their sources, charge density and current density.

Navier–Stokes equations, describe the motion of fluid substances. These equations arise from applying Newton's second law to the motion of fluid, together with the assumption that the fluid stress is the sum of a diffusing viscous term (proportional to the gradient of velocity), plus a pressure term. The equations are useful because they describe the physics of many things from modelling the weather, ocean currents, water flow in a pipe, air flow around a wing and motion of stars inside a galaxy. In their full and simplified forms help with the design of aircraft and cars, the study of blood flow, the design of power stations, the analysis of pollution, and many other things.

Boltzmann transport equation, is used to study the motion of physical quantities such as heat and charge through fluid, and thus to derive transport properties such as electrical conductivity, viscosity, and thermal conductivity. Physicists today use the equation to model gases in everything from nuclear power stations to galaxies

Heisenberg's equation of motion was the first complete and correct definition of quantum mechanics, branch of physics that study the motion of subatomic particles. It extended the Bohr model of atom by describing how the quantum jumps occur, by interpreting the physical properties of particles as matrices that evolve in time. The Heisenberg equation of motion, named after Werner Heisenberg who formulate it in 1925.

Schrödinger equation describes how the quantum state of a physical system changes in time. It is as central to quantum mechanics as Newton's laws are to classical mechanics. In the standard interpretation of quantum mechanics, the quantum state, also called a wavefunction or state vector, is the most complete description that can be given to a physical system. The equation is named after Erwin Schrödinger, who constructed it in 1926. Solutions to Schrödinger's equation describe not only molecular, atomic and subatomic systems, but also macroscopic systems, possibly even the whole universe.

In summary, scientific principles and concepts expressed through the laws, equations and formulas are the bedrock of any engineering creation. They have achieved that status by providing accurate predictions for all engineering and management concepts, scenarios and "dreams".

III. Concept of Maintainable System

At the end of production or construction process, when all consisting components are assembled together and relationships between them established, a new physical system is "born" with capability to deliver all expected functionality characteristics. That unique, infinitesimally short instant of time, is denoted as t=0, to mark the beginning of the system operational process. Thus, each system will have its own "birth" time, which is very important from the system life point of view. At that instant the system is, for the very first time in its life, able to satisfy users' needs by delivering functionality (function, performance and attributes). Hence, functionality characteristics of the system are inherited from its design process and cannot be changed during the system life, apart from implementing some modifications and redesigns.

For example, in 1969, engineers and managers of the Boeing Corporation have deliver to the world first wide body aircraft, named Boeing 747, series 100 with the known functionality characteristics.:

Passengers	
3-class configuration	366
2-class configuration	452
1-class configuration	N/A
Cargo;	6,19 ft^3 = 30 LD-1 containers
Engines maximum thrust	• Pratt & Whitney JT9D-7A 46,500 lb (20,925 kg) • Rolls-Royce RB211-524B2 50,100 lb (22,545 kg) • GE CF6-45A2 46,500 lb (20,925 kg)
Maximum Fuel Capacity	48,445 U.S. gal (183,380 L)
Maximum Takeoff Weight	735,000 lb (333,400 kg)
Maximum Range	6,100 statute miles (9,800 km)
Typical Cruise Speed at 35,000 feet	Mach 0.84 555 mph (895 km/h)
Basic Dimensions	
Wing Span	195 ft 8 in (59.6 m)
Overall Length	231 ft 10.2 in (70.6 m)
Tail Height	63 ft 5 in (19.3 m)
Interior Cabin Width	20 ft (6.1 m)

It is expected that each Boeing 747-100 series aircraft have the same functionality, under identical environmental conditions, because the laws of nature are independent of time and the location in the universe, However, experience teaches us that in-service performance of these systems is dominated by phenomena like fatigue, operator induced errors, corrosion, creep, foreign object damage, a faulty weld, bird strike, perished rubber, carburettor icing, to name just a few. These phenomena generate energy exchanges between systems and environment, leading to the loss of the design-in function or performance. Hence, maintaining the deign-in performance beyond the delivery day requires actions like troubleshooting, repairs, replacements, modifications, diagnostics, "cannibalisations" and similar to be performed.

In summary, any entity that satisfy human needs by performing a measurable function whose design-in functionality is maintained by humans is defined as a maintainable system.

IV. The Concept of Functionability

Thus, the ability of being functional through time, known as **functionability,** is an essential in-service property of maintainable systems.

From functionability point of view, at any instant of time a system can be in one of the following two states:

- Positive Functionability State, PFS, which is the state of being functional
- Negative Functionability State, NFS, which is the state of not being functional

The motion of the system through functionability states is governed by the occurrence of functionability events, which are classified as:

- Positive Functionability Events, PFE, which cause the transition from NFS to PFS
- Negative Functionability Events, NFE, which cause the transition from PFS to NFS

Consequently, the life of a maintainable system could be considered as motion of system through functionability states. The pattern generated by the motion of functionability through functionability states, in respect to the passage of time, forms the functionability trajectory.

V. Functionability Questions

One of the major concerns of design engineers and project managers are predictions of operation, maintenance and support resources required for maintaining systems in positive operational state through their life. These include diagnostic equipment, skilled and trained maintenance personnel, maintenance facilities, spare parts, inspection tools, technical data, storage facilities, means of transportations and so forth. Often the cost of these resources considerably exceeds the purchase cost of system itself. Equally, the lack of maintenance resources causes further delays in the recovery of functionality. Hence, some balance between investment in the resources and the time delays incurred by their deficiency is required. To make that trade off, engineers and managers, need to find the answer to the following functionability related questions:

- How many Negative Functionability Events are going to occur?
- What types of Negative Functionality Events are going to occur?
- What frequencies of Negative Functionability Events are going to be?
- How the cause of Negative Functionability Event will be detected?
- How long systems are going to be in Negative Functionability State?
- How long systems are going to be in Positive Functionability State?

Unlike the functionality questions to which existing laws of science readily provide the answers, the above raised functionability questions stayed unanswered. Existing equations of motion, some of which are briefly presented at the beginning of this paper, are not able to even the address the above questions, not because they are incorrect, but because they are not created to address these phenomena.

In summary, without ability to provide accurate answers to functionability questions design engineering and project management are not in the position make the trade off between the cost of resources required to maintain systems in positive functionability states and the consequential losses while they are in negative functionability states.

VI. Concept of Mirce Mechanics

The development of science started when people began to study phenomena not merely observing them. People developed instruments and learned to trust their readings, rather than to rely on their own perceptions. They recorded the results of their measurements in the form of numbers. Supplied with these numbers they began to seek relationships between them and to write down in the form of formulas. Then the formulas became the only things they came to trust when they began to predict things they could not physically experience.

Consequently, to address functionability questions the author established the MIRCE Akademy in 1999. Staff, Fellows, Members and students of the Akademy study in-service behaviour of maintainable systems to:

- Physically observe the emerging trajectory of the motion of functionability through the life of maintainable systems and to measure emerging in-service performance
- Scientifically understand mechanisms that cause the motion of a functionability through the life of maintainable systems, within the physical scale from 10^{-10} to 10^{10} metre [2,3,,4,5,6,7]
- Mathematically define the scheme for the prediction of in-service performance of a given design-in system, for a given in-service conditions and rules.

A science based body of knowledge, formulated through axioms, formulas, methods, rules and algorithms for predicting the in-service performance of the future systems, resulting from their motion through the functionability states in respect to time constitutes Mirce Mechanics.

The ability to simultaneously predict the design-in functionality performance and in-service functionability performance of the future systems is of fundamental importance for the engineers, managers, investors, regulators and other specialists who are responsible for the satisfaction of the "human felt needs", in reliable, economical and safe manner, for the future transportation, communication, defence, energy, entertainment and many other functions delivered by maintainable systems.

VII. The Concept of Motion in Mirce Mechanics

Motion is one of the most complex concepts of science. The images it creates in our minds are diverse as the "jiggling" of atoms and molecules to the movement of planets, and beyond.

Since the earliest years of science the only idea of motion imagined was that of mechanical motion, so there is a tendency to view all other kinds of motion in terms of the concept of trajectory. As the science progressed, this naturally became impossible, for instance when the attempt was made to conceive the electrical motion. It could be possible, of course, to think in the case of a high-voltage transmission line that wire is the "trajectory" of the electric signals. However, such a mental picture would have no practical purpose, as the electromagnetic waves could not have been viewed as a liquid flowing through the wires.

Consequently, the question by which the motion of functionability through the life of maintainable systems is to be described must contain only those quantities that can be measured physically. Research performed shown that it could only be seen as the change in the functionability state of a system through time. Hence, a life of any maintainable system could be viewed as a sequence of occurrences of positive and negative functionability events that "move" systems through functionability states.

In summary, in Mirce Mechanics the motion of functionability is perceived as the change in the functionability state of a system in relation to functionability state variables, with respect to the passage of time. Functionability state variables are measures of functionality performance of a system that uniquely determine the functionability states of a system.

VIII. Mechanisms of Motion

As statistics does not study the cause of statistical behaviour, to understand that motion of functionability it was necessary to scientifically analyse the mechanisms that generate functionability events.

To understand the mechanisms that generate negative functionability events analysis of over tens of thousands of components, modules and assemblies of systems in defence, aerospace, transportation, motorsport, nuclear, communication and other industries, had been studied at the MIRCE Akademy. As it has a profound impact on all aspects of the in-service life on any maintainable system several research studies have been performed by the Master and Doctoral students of the MIRCE Akademy with aim to understand the physical mechanisms that caused their occurrences.

All physical phenomena that cause the motion of a system from the positive to negative functionability states are known as negative functionability events. Mechanisms that generate negative functionability events belong to the following three categories:

- Overstress mechanisms, where acting stresses generated by mechanical, electrical, thermal, radiation, chemical and other type of energy exceed that strength of components and systems subjected, resulting from phenomena like foreign object damage (birds, hail, rain, snow), lightening, abuse by operators, maintenance errors and similar
- Wearout mechanisms, where cumulative damage, generated by mechanical, electrical, thermal, radiation, chemical and other type of energy, is accumulated through processes like, corrosion, fatigue, creep, wear and similar.
- Human actions, where the transition from positive to negative state results from direct decision taken by humans. Most frequently these actions are performed as a part of scheduled maintenance tasks performed to check the state of a system, to preventively replace predetermined components or to install modified components.

All physical phenomena that cause the motion of a system from the negative to positive functionability states are known as positive functionability events. Mechanisms that generate positive events belong to the following categories [8]:

- Servicing: replenishment of consumable fluids, cleaning, washing, painting, etc.
- Lubrication: installing or replenishing lubricant.
- Inspection: Examination of an item against a defined physical standard.
- General visual inspection: performed to detect obvious unsatisfactory conditions.
- It may require the removal of panels and access doors, work stands, ladders, and may be required to gain access.
- Detailed visual inspection: consists of intensive visual search for evidence of any irregularity. Inspection aids, like mirrors, special lighting, hand lens, boroscopes, etc. are usually required. Surface cleaning may be required, as well as elaborate access procedure.
- Special visual inspection: an intensive examination of specific area using special inspection equipment such as radiography, thermography, dye penetrant, eddies current, high power magnification or other NDT. Elaborate access and detailed disassembly may be required.
- Check: a qualitative or quantitative assessment of function.
- Examination: a quantitative assessment of one/more functions on an item to determine whether it performs within acceptable limits.
- Operational: a qualitative assessment to determine whether an item is fulfilling its intended function. It does not require quantitative tolerances.
- Restoration: perform to return an item to a specific standard. This may involve cleaning, repair, replacement or overhaul.
- Discard: removal of an item from service.

All of the above listed mechanisms of the motion of systems through positive and negative functionability states are observable physical processes or recognisable human actions. [9]

IX. Mathematics of Motion in Mirce Mechanics

Results of experiments and observations performed thus far unquestionably lead to conclusion that the deterministic regularity found in the continuous motion of functionality, such as speed, acceleration and similar, studied by classical mechanics, cannot be found in respect to the motion of functionality through time. What can be found is discrete motion with statistical variability, as shown in Figure 1.

Thus, functionality trajectories, generated by similar individual systems, under similar circumstances vary among them self, to the degree that no two trajectories are identical. Therefore, the proven formulas of Newtonian mechanics that govern the motion of macroscopic bodies through time cannot be used for predicting the motion of functionality through time, as far as the functionality trajectory is concerned

The relative frequency histogram of the motion of functionality through the life of sample size of 497 systems at specific instances of time is obtained by using well known statistical expression:

$$y'(t) = \frac{\text{Number fo systems in PFS @ t}}{\text{Total Number of Systems Orserved}} \quad 1.$$

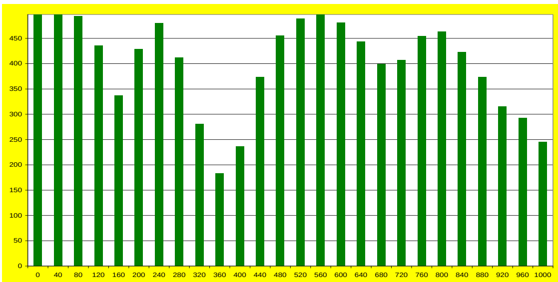

Figure 1: Relative Frequency Histogram of the Motion of Functionality through the life of 497 Systems at specific instances of time

Clearly, functionability histograms can be produced only after the data have been generated, which means after the events. However, the objective of Mirce Mechanics is to develop equation that will be able to predict the data that are going to be observed, in the similar manner as the predictions made by Newton's, Maxwell's, Schrödinger's become confirmed by the future events.

Mirce Mechanics Formulas, developed at the MIRCE Akademy, by D Knezevic, are mathematical expressions of the physically observed processes of the motion of systems through functionality states and they define and predict physically measurable properties of system functionability in the probabilistic terms.

The laws of probability are just as rigorous as other mathematical laws. However, they do have certain unusual features and clearly delineated domain of application. For example, it can be readily verify that in the case of a large number of systems failure phenomena will occur in a specific number of the cases, and the law is more accurate the more systems are observed. However, this accurate knowledge will be of no help in predicting the occurrence of functionability events in each individual case. This is what distinguishes the laws of probability: the concept of probability is valid only for an individual event and it is possible to work out a number that corresponds to it. However, it can only be measured when identical tests are repeated a great number of times. Only then can the measured value, the probability, be used to assess the occurrence of each individual functionability event, which is one of the possible outcomes of the test.

The unusual features of the laws of probability have a natural explanation. In fact, most probabilistic events are results of quite complex physical processes, which in many cases cannot be studied or understood in all of its intricacy. Such inability takes its toll, as it is only possible to predict with certainty the average result of numerous identical tests. Thus, for each functionability event it is only possible to indicate its likely outcome.

Probabilistic predictions of the functionability trajectory are based on the framework of the sequence of occurrences of Positive and Negative Functionability Events, whose individual and cumulative times are measured as shown in the Figure below.

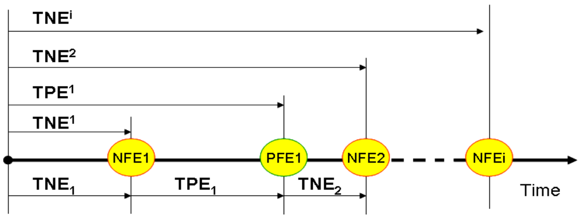

Figure 2: Individual and Cumulative Times to Functionability Events

Based on the Figure 2, the following functions are used:

Negative Function, $F_i(t)$, which defines the probability that the i^{th} NFE will take place before or at instant of time t is defined in the following way:

$$F_i(t) = P(TNE_i \le t), \ i = 1, \infty \,. \quad 2.$$

Positive Function, $O_i(t)$, which define the probability that the i^{th} PFE will take place before or at instant of time t is defined by the following expression:

$$O_i(t) = P(TPE_i \le t), \ i = 1, \infty \,. \quad 3.$$

Probability distribution that defines this event is uniquely determined by the physical properties of the process that generate positive functionability event (replacement, repair, calibration, modification and similar) [9].

Sequential Negative Function, $F^i(t)$, which defines the probability that the ith sequential NFE will take place before or at instant of time t, is defined as:

$$F^i(t) = P(TNE^i \le t),\ i = 1, \infty. \qquad 4.$$

Sequential Positive Function, $O^i(t)$, which defines the probability that the ith sequential PFE will take place before or at instant of time t: is presented in the following manner:

$$O^i(t) = P(TPE^i \le t),\ i = 1, \infty. \qquad 5.$$

Equations E3 and E4 define the sequence of functionability events for any maintainable system. Having determined the probability distribution and its governing parameters of the times to subsequent functionability event, positive and negative, it is possible to develop a mathematical scheme that will provide opportunity to predict the future sequence of functionability events for any given system. This is the essence of the Mirce Mechanics, which is the only theory available to design engineers to quantitatively predict the consequences of all of their decisions on in-service behaviour of their future systems.

X. Mirce Functionability Equation

The trajectory of functionability is uniquely defined by the sequence of functionability events, from the birth of the system to its decommissioning. Thus, the fundamental equation of Mirce Mechanics, the functionability equation y(t), that defines the probability of a system being functionable at a given instant of time t is defined as:

$$y(t) = P(PFS@t)$$

$$= \sum_{i=0}^{\infty}\left[P(PFS^i @ t)\right]$$

$$= \sum_{i=0}^{\infty}\left[P\left(TPE^i \le t\right) - P\left(TNE^{i+1} \le t\right)\right]$$

Making use of equations 3 and 4, while bearing in mind that $O_0(0) = 1$, as a system starts its life in positive functionability state, the above expression of functionability equation could be presented in its final form:

$$y(t) = 1 - \varphi(t) + \mu(t) \qquad 6.$$

where:

$\varphi(t) = \sum_{i=1}^{\infty} P(TNE^i \le t)$ is the expected number of negative functionability events that will take place from the birth of a system and a given instant of time t.

$\mu(t) = \sum_{i=1}^{\infty} P(TPE^i \le t)$ is the expected number of positive functionability events that will take place from the birth of a system and a given instant of time t.

This expression is developed by the author and it is named Mirce Functionability Equation. It defines the trajectory of a functionability through the probability of a system being in positive functionability state at a given instant of time t.

The unit of functionability determined in accordance to the Mirce Functionability Equation, .is 1 Senna [1S]. It is quantified by the probability of maintainable system being in PFS at a given instant of time.

Making use of existing observational data related to the in-service behaviour of a sample of 497 systems, operating in similar environmental and utilisation conditions, the probability laws that drive shapes of positive and negative functions defined by the equations 2-5 where determined. The obtained functions are shown in Figure 3, where the green lines represent positive functions and the read lines represents negative functions.

The functionability trajectory, calculated in accordance to the expression 6 is shown with a black line in the Figure 3.

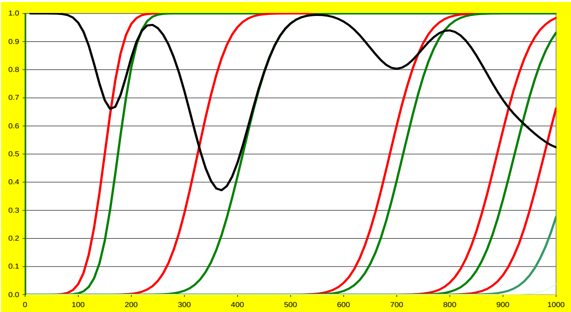

Figure 3: Functionability profile calculated by Mirce Functionability Equation for the Example shown in Figure 1.

Analytical solutions for the Mirce Functionability Equation are seldom possible due to inability of mathematics to deal with the large number of functions and their interactions. These types of problems are not specifically related to the Mirce Mechanics; they are common to all scientific disciplines of this nature, as it is a known mathematical fact that the integral equations do not have analytical solutions. [10]

However, it is necessary to develop computational methods to deal with the mathematical difficulties as it is unacceptable to simplify observed reality of system in-service behaviour in order to cope with mathematical limitations. [11]

For the numerical example used in this paper the result of the application of the Monte Carlo simulation method performed to obtained quantitative solution of the Mirce Functionality Equation is shown in Figure 4 as dots.

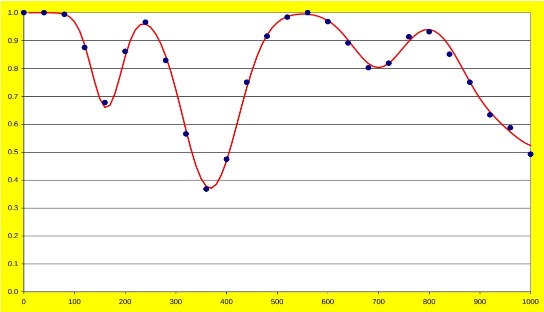

Figure 4: Functionability profile calculated by Mirce Functionability Equation

XI. The Impact of Mirce Functionability Equation on System Engineering and Management

Although science has to be truthful, rather then useful, the body of knowledge of Mirce Mechanics is essential for scientists, mathematicians, engineers, managers, technicians and analysts in industry, government and academia to predict functionability trajectories of the future systems, for a given configurations, in-service rules and conditions, in order to manage functionability events in the way that the functionability performance is delivered through the life of system, at least investment in resources and environmental impact. For that to happened, the science proven method is needed, very much different from the classical scientific knowledge, described trough the type of the equations mentioned in the introductory part of the paper, because functionability performance are defined in the following way:

- Every scheduled flight will leave on time with a probability of at least 0.97 or in other words, it is acceptable to have no more than three delays, on average, out of 100 flights;
- The direct maintenance cost will not exceed 25 % of the purchase cost with a probability of 0.95;
- The probability that the production line will be fully operational during the specified in-service time will be not less than 0.91;
- In system consisting of several systems, at least 90% of them will be operational at all times with a probability not less than 0.925;
- The mission reliability will be greater than 0.98 for missions shorter than 500 hours;
- There should be 5 NFEs among 1000 systems, on average, during the first 10 years of service, with a probability of 0.95.
- Each 10 hour flight will be successfully completed with probability of 0.995, during the first 20 years of operation

Consequently, the only way to address performance targets formulated in the way above is to use concept and principles of Mirce Mechanics to evaluate engineering and management options, at the time when fundamental and irreversible decision are made regarding future systems.

XII. Conclusion

This paper clearly demonstrates that functionability performance of any maintainable system is very much different from its functionality performance, in physical, technical, engineering and management sense.

This paper also demonstrates that functionability performance is the time dependent property of the system and its motion is manifested through the sequence of transitions through positive and negative functionability states.

Like in the classical mechanics, where the continuous uniform motion is natural state of the macro world that is fully defined and predictable by Newton's equations, or in quantum mechanics where the continuous motion is also natural state of a micro world fully described and predictable by Schrodinger equation, in Mirce Mechanics continuous change in the functionability states is a natural state of maintainable systems during they in-service life, which is fully defined and predictable by Mirce Functionability Equation.

Finally, Mirce Functionability Equation is the scientific foundation of the System Engineering and Management predictions and analysis regarding the motion of functionability through the life of maintainable system.

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