MIRCE PROFITABILITY EQUATION

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Preliminary notes

SUMMARY

Commonly, maintenance is perceived as "fixing broken things". As such, it is associated with failure consequences and unplanned expenses, both of which negatively impact business plans or customer satisfaction. However, as failures are an inevitability of the life of any technological system, it would be worthwhile to start looking at maintenance as opportunity for dealing with them and making t positive impact on business plans or customer satisfaction, while generating profit. Thus, the main objective of this paper is to present the Mirce Mechanics approach to maintenance that is focused on the way that failures, once scientifically understood, could be managed in the way that reduces the number of in-service interruptions and operational costs, which in turn will generate profit for private companies or increases the effectiveness of public services like health, transportation, tourism up to the national defense. Finally, the development of the Mirce Profitability Equation has been presented in the paper, which is the bed rock of this approach.

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Mirce Mechanics, Failure Management, Profitability

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1. INTRODUCTION

The main business of business is to stay in business. To stay in business the expected "business function" must be provided through time at minimum investment in resources. Hence, the generated profit is equal to the revenue generated by the monetary value of the "business function", *R*, minus the cost of the resources used to run the business, *C*, during a given interval of time *T*, $P(T)=R(T)-C(T)$. Hence, the main concerns of the owners and users of industrial systems are related to how much of the "business function" will be delivered during the life time of a system and how much maintenance and support efforts are expected from them to keep the system going[1]. For example, the business function of a passenger aircraft is to transport a passenger and cargo trough air over a life time of 25-30 years. To stay in business an airline is required to maintain it in airworthy condition. Hence, for each of the business processes these two main factors are obtained at the end of each financial year or at the end of the industrial system. [1]

This, type of performance, of industrial/business systems is known as functionability[2] performance. Regrettably, producers/constructors of industrial systems do not provide answers to this type of performance on the delivery day. Instead, years later the statistics for various functionability measures become available. The reason for this is the fact that in-service behaviour of industrial systems is governed by the complex processes that are governed by the laws of science, human rules and environmental impacts, which are characterised by indeterminism, irreversibility, inseparability, and dependence on time, location and humans.

Consequently, the main objective of this paper is to present the Mirce Mechanics approach to functionability, as scientific foundation of keeping system in business through failure management. It is focused on the way that failures, once scientifically understood, could be managed in the way to maximise the time in operation and minimise the time in maintenance, which in turn will generate profit for private businesses or increase public satisfaction for common services like health, transportation, education, tourism all way up to the national defence.

[1] Boeing 747, registration number N747PA, which belonged to Pan Am transportation system, have delivered the work of 80,000 flying hours and received 806,000 maintenance man-hours, during the 22 years of in-service life

[2] Functionability, n, defined as the ability of being functional through life, in the book Reliability, Maintainability and Supportability – A probabilistic Approach, by J. Knezevic, pp. 291, McGraw Hill, London 1993. ISBN 0-07-707691-5

The paper is also showing the development process of the Mirce Profitability Equation, as a scientific foundation of a rational to maintenance based on Mirce Mechanics which should increase business competitiveness or public satisfaction f any organisation that is willing to apply it to the process of manging business processs, from reliability, cost and profitability point of view.

2. 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 "business as usual" state through their lives. 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 keeping systems in the "out of business" state. 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 Failures are going to occur?
- What types of Failures are going to occur?
- What frequencies of Failures are going to be?
- How Failures will be detected?
- How long systems are going to be "out of business"?
- What resources are needed to return it to the "business"?

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 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 manager are not in the position make the trade off between the cost of resources required to maintain systems in "business as usual" state and the consequential losses while the system is "out of business" state, also known as the "failed state".

3. TYPES OF FAILURES

In order to better manage failure, it helps to understand that there are two consequences of failure: those affecting safety and those affecting the economics of business (revenue, profit, reputation, etc.). Thus:

- Safety related failures are those that jeopardises the safety of the industrial system or places in peril environment or humans must be prevented. Safety significant industrial systems, like aircraft, submarine, train, nuclear reactor and similar cannot be of such design that any single failure of the device will have catastrophic results. This is safety engineering dogma. Today's industrial systems of this type are subject to very few critical failure modes. This safety-related reliability is attributed to the design requirements of the relevant governmental regulations as well as the specifications of operating organizations and manufacturers. Current design practice ensures that vital functions are protected, which means, that, if there is failure, a given function will remain available from other sources to insure a safe completion of operation.
- Economic related failures are those where the loss or deterioration of a particular function neither endangers the industrial system nor its environment, but it affects the "business" state of a system. Examples include systems, components, or features in a design that are not specifically required to demonstrate conformity to the basis of safety certifications. However, a failure of a single components or module can cause the loss of functionability of the industrial system and causes a loss of business until repair or replacement is accomplished.

Based on the above, it possible to conclude that one of the fundamental "business" questions is how to manage failures that take a "business out of business" at the most cost effective manner?

4. MANAGEMNT OF FAILURES

The most effective way of managing failures is to address them at the early stages of design. Generally speaking there are two main design solutions for minimising the amount of time during which the system is in "not in business" state. Thus:

- The components and systems to be designed to an exceptional degree of reliability by selecting "exotic materials", high kevel of tolerances, extensive testing and similar solutions. This could be an inordinately costly strategy. Cost-effective design trades must be made between the loss of functionability arising from a system being in "not in business" state situations and the cost of exceptionally reliable components.
- Minimising the time that a system spends in "not in business" state. The design approach embraces the incorporation of features that are extra to those required for safety certifications. These include:
  - redundancy,
  - fault tolerance
  - fail safe,
  - fail passive features
  - group replacement.

  It is necessary to stress that all of these efforts are beyond those required to certify the safe design of industrial system. Of course, this is not without its price, however. It increases the number of failure possibilities, adds more items that can fail, and results in equipment that is more complex and integrated — making fault isolation more difficult. It adds to the cost of the industrial system, so it must be done carefully to keep costs under control.

Regarding this fundamental design options, Jack Hessburg[3], the Chief Mechanic of the Boeing New Airplanes (1990-1999), has said "*I as a designer I have to fill my customer in as well, I have to decide where I'm going to put economic redundancy into my design, because it costs money. If you have the full answer to that, would you please see me after this meeting! There's a Nobel Prize in it. We have really not developed the discipline where we know how to normalise that, yet.*"

[3] Jack Hessburg 27th January 1998, M.I.R.C.E. Industrial Lecture, Exeter University, UK.

5. THE MIRCE MECHANICS

The author of the paper could not have seen how to proceed with his research, challenge initiated by Jack Hessburg, within departmentalised academic institutions and training processes. Hence, he left the School of Engineering at Exeter University in UK and start an independent research, education and training organisation, named the MIRCE Akademy at Woodbury Park, Exeter, UK, in 1999, with only one clear statement of intent "Never to departmentalise any research activities." Staff, Fellows, Members and students of the Akademy have endeavoured to subject in-service behaviour of industrial systems to the laws of science and mathematics to:

- Determine the trajectory of the motion of industrial system through functionability states, which is defined by the sequence of occurrences of positive and negative functionability events, resulting from the atomic, environmental and human actions. Understand mechanisms that lead to the occurrence of functionability events starting from atomic structure that drives the behaviour of matter, up to the solar system that drives the energy conversions (a physical scale ranging from 10^{-10} to 10^{10} metre).
- Define a mathematical scheme for predicting expected in-service functionability measures of a given industrial system together with the expected work done on the system under a given maintenance policies and planned support strategy.

While in classical mechanics a force is said to do work if, when acting on a body, there is a displacement of the point of application in the direction of the force, in Mirce Mechanics a given system is said to do work, if there is a provision of measurable functions in the direction of time, which is exactly what is expected from a business. In summary, the body of knowledge comprising of axioms, mathematical equations and methods that enable engineering, predicting and managing the functionability performance of industrial systems, based on the scientific understanding of the mechanisms that drive an industrial system through states "business as usual" and "out of business" through the life, constitutes Mirce Mechanics.

6. 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 industrial systems through functionability/business states through time must contain only those quantities that can be measured physically. Research performed shown that a life of any industrial system could be viewed as a sequence of occurrences of positive and negative functionability events that "move" systems through functionability/ business states.

Functionability state variables uniquely determine the functionability states of a system.

The motion of Industrial Systems through functionability states stays is result of imposing physical processes or human decisions, jointly called imposing actions. To understand the mechanisms that generate those actions analysis of tens of thousands of components, modules and assemblies of systems in defence, aerospace, nuclear, transportation, motorsport, 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 industrial system, several research studies have been performed by the Master and Doctoral students of the MIRCE Akademy [2,3,4]. All physical phenomena that cause the motion of a system from the positive to negative functionability states are known as negative functionability events. Actions that generate negative functionability events belong to the following categories:

- **Inherent actions,** generated by mechanical, electrical, thermal, radiation, chemical and other types of energy, that have been introduced into system prior to the operation process through activates associated with manufacturing, transportation, maintenance, storage and similar processes.
- **Potential actions,** generated by mechanical, electrical, thermal, radiation, chemical and other types of energy, that exceed the strength of components and systems subjected, resulting from phenomena like foreign object damage (birds, hail, rain, snow), lightening, abuse by operator (pilots, driver and user errors), single event upset [3] and similar.
- **Continuous actions,** generated by mechanical, electrical, thermal, radiation, chemical and other type of energy, that continuously act on a system through in-service life of systems and generate processes like, corrosion, fatigue, creep, wear and similar, which are result of natural decay of matter.

All physical actions that cause the motion of a component or a module from the negative to positive functionability states are known as positive functionability events. Mechanisms that generate positive events belong to the following categories [6]:

- Servicing: replenishment of consumable fluids, cleaning, washing and similar.
- 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 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. [5]

7. MIRCE FUNCTIONABILITY EQUATION

Results of experiments and observations performed over several decades by the author unquestionably lead to conclusion that the deterministic regularity found in the predictions based on continuous motion through time, such as speed, acceleration and similar, studied by classical mechanics, cannot be found in respect to the motion of functionability through time. Thus, trajectories, generated by the motion of individual copies of a given system type, under similar in-service conditions, demonstrate variability, 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 functionability through time, as far as the functionability trajectory is concerned Thus, Mirce Mechanics Formulas, developed at the MIRCE Akademy, by D Knezevic, are mathematical expressions of the physically observed processes of the motion of industrial systems through functionability states and they define and predict physically measurable properties of system functionability performance 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.
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. Probabilistic predictions of the functionability trajectory are based on the framework of the sequence of occurrences of functionability events, positive and negative, which are occurring with a probabilistic regularity.

Having determined the probability distribution and its governing parameters of the times to subsequent functionability events, it is possible to develop a mathematical scheme that will provide opportunity to predict the future sequence of functionability events for any given industrial system. This is the essence of the Mirce Mechanics, which is the only theory available to design engineers and project managers to quantitatively predict the consequences of all of their decisions on in-service behaviour of their future systems and their “business” performances.

The trajectory of the motion of an industrial/business system through functionability states is uniquely defined by the sequence of occurrences of functionability events, from the birth of the system to its decommissioning. Thus, the fundamental equation of Mirce Mechanics, the Mirce Functionability Equation [7] and it defines the probability of an industrial system being in positive functionability state or “business as usual” state, at a given instant of time t, thus::

$$y(t) = P(PFS\ @\ t) = 1 - \varphi(t) + \mu(t)$$

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 and $\mu(t) = \sum_{i=1}^{\infty} P(TPE^i \le t)$ 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.

Finally, the work done by an industrial system during the stated interval of time T, $W_{by}(T)$, can be calculated by making a use of the following expression:

$$W_{by}(T) = \int_0^T y(t)dt \qquad [\mathrm{Hr}]$$

Hence, the numerical value of the above expression presents the amount of time during which a given industrial system will be in the state of"business as usual" during the stated calendar time T

For the most generic case, where the business can be only in the state of "business as usual" and the "not in business", the work done to the system is determined by the following expression:

$$W_{to}(T) = T - W_{by}(T) \qquad [\mathrm{Hr}]$$

8. MIRCE PROFITABILITY EQUATION

The creation of Mirce Functionability Equation enabled calculation of the work done by the system, during a stated period of time T. That enabled the development of the Mirce Profitability Equation that links the revenue and cost sides of business at one place as a function of the engineering configurations of a system, adopted business methods associated with the relevant project management decisions and characteristics.

Thus the expected revenue of a given industrial system, during the stated interval of time, *R(T),* expressed in the monetary units, MU, is equal to the product of the Hourly Income generated by the provision of business function, HI and the amount of the work done by the system, thus:

$$R(T) = HI \times W_{by}(T) \qquad [MU]$$

In general term, the cost of doing business during the state period of time, is equal to the sum of the cost of operation, *CO(T)*, which is equal to the sum of the fix cost of operation, $CO_{fix}(T)$ and variable cost of operation that is equal to the product of the Hourly Cost of Operation, HC_{op} and the work done by the system, hence

$$CO(T) = CO_{fix}(T) + HC_{op} \times W_{by}(T) \qquad [MU]$$

Equivalent cost for maintaining a system in the "business as usual" state, during the stated period of time, *CM(T)*, which is equal to the sum of the fix cost of maintenance, $CM_{fix}(T)$ and variable cost of maintenance that is equal to the product of the Hourly Cost of Maintenance, HC_{mt} and the work done to the system, hence:

$$CM(T) = CM_{fix}(T) + HC_{mt} \times W_{to}(T) \qquad [MU]$$

Finally, the profit expected to be generated by a given industrial system, during the stated period of time, could be calculated by making use of the Mirce Profitability Equation, thus:

$$\begin{aligned} P(T) &= R(T) - C(T) \qquad [MU] \\ &= \left\{HI \times W_{by}(T)\right\} - \left[CO(T) + CM(T)\right] \\ &= HI \times W_{by}(T) - \left\{\left[CO_{fix}(T) + HC_{op} \times W_{by}(T)\right] + \left[CM_{fix}(T) + HC_{mt} \times W_{to}(T)\right]\right\} \end{aligned}$$

In summary the above equation is the only one, known to the author, which unifies all aspects of in-service performance of an industrial/business system. It enables the accurate predictions of the expected profit to be made for each operational scenario, maintenance policy and support strategy. The above equation "unites" the whole organisation into an analytical scheme, rather than to be a collection of a large number of self standing models that address a few components of the time, or a few performance parameters of the system.

System effectiveness is an emerging property of a in-service life of a system generated by the complex and time dependent interactions of the following properties:

- Functionality principles of a system (mechanical, electronic, thermal, electrical, nuclear, etc.)
- Structure/construction of a system (dependencies and redundancies)
- Operational concepts and scenarios (continuous, seasonal, one off)
- Maintenance rules (schedule inspections, replacement, testing and so forth)
- Support Strategies (training, spares, facilities, tools, equipment, etc.)
- Environmental conditions (climate and weather)

10. THE IMPACT OF MAINTENNACE ON PROFITABILITY

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 the work done by the system and to the system , for a given configurations, in-service rules and conditions, in order to manage failures 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, because functionability performance is 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 during the first 10 years 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 up to 500 hours;
- 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 functionability 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 the management of failures of future industrial systems.

10. CONCLUSION

The main objective of this presentation is to present the Mirce Mechanics approach to failure management process regarding the increase in profitability of industrial systems, as a new approach to maintenance. It is focused on the way that failures, once scientifically understood, could be managed in the way to maximise the time in operation and minimise the time in maintenance, which in turn will generate profit for private businesses or increase public satisfaction for common services like health, transportation, education, tourism all way up to the national defence.

Unlike 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, in Mirce Mechanics continuous change in the functionability states is a natural state of industrial systems during their in-service life, which is fully defined and predictable by Mirce Functionability Equation. Finally, Mirce Profitability Equation is presented as the scientific foundation of the System Engineering and Management predictions and analysis that brings together the revenue and cost elements of businesses that are dependent on the behaviour of industrial systems.

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