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Dr. Jezdimir Knezevic

The Job of RMS Community is Provisioning of Work by Maintainable Systems

Author's Note: This paper is dedicated to the life of Sarah Palmer-Tompkins (23.12.1971-8.2.2017) a person whom I never met but her genuine, sincere and cheeky attitude towards life constantly generated a unique smile in me, during her well-covered public appearances.

> *"Airlines are in the transportation business; Boeing, Douglas, Lockheed, Airbus, they're in the airplane business. You can have the shiniest looking airplane in the world, the most remarkably engineered airplane in the world, it's an academic marvel, it's an engineering marvel, but if the damned thing is not at B3 in Chicago at 9.15 to originate the trip to Cleveland, forget it."*
>
> **Jack Hessburg, (1934-2013)**
> Grand Fellow of the MIRCE Akademy

1. Introduction

Since its beginnings in late 1950s, the Reliability, Maintainability and Supportability, RMS, theories have been based on mathematical theorems rather then on scientific principles. Hence, massive attempts were made to further the applications of the existing mathematical and operational research methods and analyses without understanding "the functionability mechanics."[1] Then, in the mid 1980s, practicing RMS engineers and analysts, who did not have neither ability nor need to understand the mathematics, turned to what they have had, enormous practical experience and analysis like FMECA, MTA, LORA, LSA, LCC and many others were created and applied to the design of maintainable systems. Thus, a large number of the best practices for RMS analysis of the new systems have been developed and used, but still without understanding and addressing "the functionability mechanics". Consequently, during the last 60 years the RMS theories made very little progress, if any, in the direction of becoming the science based foundation for RMS engineering and management profession. The reason is very simple; it has been between the mathematicians who did not have in-service engineering experience and in-service engineers who did not have mathematical skills and yet are put in the design office to perform RMS predictions and influence the design process that is dominated by engineers whose methods and skills are based on the principles of fundamental sciences, like mechanics, thermodynamics, material science, fluid mechanics and so forth.

Even further, a majority of the RMS method based on best practises and governing industrial/military standards address specific in-service characteristics of the components of maintainable systems alone, like reliability, maintainability, supportability, testability, availability and similar. However, in the late 1990s the author became fully aware that, despite the fact all of these specialist subjects have their own specifications and contractual requirements, there was nothing to

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[1] Functionability mechanics is a part of the Mirce-mechanics that scientifically studies the physical mechanisms and human actions that cause the motion of a maintainable system through functionable and non-functionable states throughout their in-service lives. Dr J. Knezevic

THIS EDITION

Published Quarterly

Russell A. Vacante, Ph.D.

Space the Final Frontier—for Reliability

Star Trek coined the expression "space, the Final Frontier." The science fiction series demonstrated the possibility of engaging in extended space travel for years at a time. The TV series and subsequent movies captured our interest in space travel and imagination for new technologies. For technical professionals, it also communicated an important technical message, namely, that space exploration systems of systems must be highly reliable and relatively easy to use. Some have even argued that the Star Trek series inspired NASA's Space Shuttle program. Indeed, the first orbiter of the Space Shuttle fleet was named after the spacecraft from the TV show.

By extension, our technical achievements related to space travel provide us an opportunity for lessons-learned that can be applicable to many other types of systems of systems. One major example is the application of lessons learned in space

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“normalise” them and predict the overall in-service performance of maintainable systems on the “drawing board”. Hence, it was impossible to even address the questions how many daily flights “to Cleveland” are likely to be delivered on time during the in-service life of a given aircraft design or how much electrical energy will be delivered by a given design option for a power station or any other measure of functionability performance of maintainable systems.

Hence, it became crystal clear to the author that the purpose of every maintainable system is *not* to deliver MTBF, MTTR, MLDT, MTTS and similar contractually required measures of RMS. Their purpose is to do the work[2]. Nothing is intentionally specified, designed, produced and acquired by somebody in order to do nothing. To be in the position to fully address the complex problem of generating accurate predictions of the work done and resources required to support operation and maintenance of maintainable systems, throughout their in-service life, the author resigned from Exeter University, UK, in 1999 and established the MIRCE Akademy at Woodbury Park, Exeter, UK.

2. A Few Words about Mirce-mechanics

> *“A theory can be proved by experiment; but no path leads from experiment to the birth of a theory.”*
>
> **Albert Einstein**

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 them 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.

QUIZ YOURSELF

When reliability modeling and comparing repairable with non- repairable systems, which method would you not use?

A) Reliability Growth - Duane
B) Weibull
C) Sabermetrics
D) Event series (Point processes)

See page 4 for the answer!

However, people communicate with each other by means of words, not formulas. Hence, when they want to speak about new phenomena they have to invent concepts that correspond to them. Even though these concepts are often quite extraordinary, people become accustomed to them and learn to apply them correctly and even create images for themselves that they associate with the new concepts.

Years of intensive research at the MIRCE Akademy have generated a new, science-based, body of knowledge, named Mirce-mechanics. It comprises axioms, laws, mathematical equations and calculation methods that enable accurate predictions of the work done by the maintainable system and the work required to be done on the system to maintain the flow of functionality through in-service life [1]. Thus, from now on, design teams will be able to “normalise” all feasible solutions regarding all relevant RMS issues at the system level, in an integrated and mutually related manner, by using Mirce-mechanics obtained predictions of functionability performance to compare all feasible options to select the most suitable compromise for all stake holders, based on their through life needs. It is an imperative, as a maintainable system comprises not only the entity delivering functionality performance but also functionability performance, which is governed by every facet of the universe that is needed to operate, maintain and support it. This includes, but is not limited to: the time it is intended to operate; the capacity it has to do work in a given time; the supplies and resources required to sustain and maintain its operation; the capability of the supplies and resources to provide sustainment and maintenance, the environment around it (weather, dust, contaminants), location (global and installed), access (physical and operational), financial constraints and many more. [2]

The main objective of Mirce-mechanics is to provide a platform for design engineers, scientists, operators, maintainers, logisticians, programmers, planners, budget managers, economists to get involved into the complexity of the process of quantifying the consequences of their specialist decisions, usually at the components and modules level, on the functionability performance of a given[3] maintainable system in the future.

3. A Few Words About the Laws of Probability

The role of probability in Mirce-mechanics is one of prediction. In classical science two identical tests under identical conditions should always yield the same end result. This is the idea behind classical causality, or determinism. However, in Mirce-mechanics causality is peculiar in that even under invariable conditions it

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[2] In Mirce-mechanics, the work is considered to be done by a maintainable system when, at least one, measurable function is delivered at a unit time. (Dr J.Knezevic)

[3] In Mirce-mechanics, a given maintainable system is defined through the following elements: 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), Logistics support (training, spares, facilities, tools, equipment, etc.) and Environmental conditions (climate and weather).

can only give the probability of the occurrence of a functionability event in a single test; on the other hand, it can, with absolute certainty, predict the distribution of occurrence of functionability event for a maintainable system type.

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 verified that in the case of a large number of systems a specific functionability event 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 that particular functionability event to each individual system. 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 chances of occurrence of each individual functionability event, which is one of the possible outcomes of the in-service life.

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

In everyday terms the expression "each event has its own cause" needs no further explanation. Causality in science requires a law to guide us through the sequence of events in time. Mathematically, this law takes the form of a differential equation, known as an equation of motion. In classical mechanics such equations, Newton's equations of motion, enable us to predict the trajectory of a particle's motion and many other natural phenomena defined by the laws of science that accurately predict functionality performance of a maintainable system.

However, in Mirce-mechanics such causality cannot be found. What is found is a statistical causality that can only be predicted through probabilistic distributions. However, probabilistic based laws are even more powerful than those laws that govern mechanical deterministic relationships, since it identifies and singles out patterns in the "chaos of possible random events". Phrases like "statistical causality" and "probabilistic regularity" could sound very strange to the deterministically minded people, but in Mirce-mechanics it is only possible to utilise them when dealing with functionability phenomena, like wear, thermal deformation, corrosion, no-fault-found, creep, bird strike, battlefield damage, bogus part, transport damage, fatigue, and many others. In fact, there is no logical paradox here as the concepts of "probability" and "regularity" are complementary ones. Hence, the starting axiom of Mirce-mechanics is that probability is a property inherent in the motion of functionability phenomena through the life of maintainable systems, rather than a convenient mathematical trick used to account for observational evidence.

4. Mirce-mechanics Equation for Work of Maintainable Systems

According to the Mirce-mechanics a work is done when a maintainable system considered delivers functionality at a unit of time. To deliver functionality system must be being in functionable state. Thus, the expected work done by maintainable system type during a given interval of calendar time, *W(T)*, measured in Senna Hours, [*SHrs*], can be calculated by making use of the following equation (Equation1):

$$W(T) = \int_0^T y(t)dt \qquad [SHrs]$$

where *y(t)* is the quantity of work done at a unit time that is quantitatively defined by Mirce Functionability Equation (Equation2) [3]:

$$y_S(t) = 1 - \varphi_S(t) + \mu_S(t) \qquad [S]$$

In the Equation 2 in-services measurable variables $\varphi_S(t)$ and $\mu_S(t)$ represents the expected number of functionability events that cause transitions of a maintainable system to non-functionable state from its birth to the given instant of time t and the expected number of functionability events that return the system in the functionable state in the given interval of time, correspondingly. The later one comprises of the time a system spends in active maintenance and the time the system spends in support (waiting for spares, trained personnel, tools, equipment, facilities and other necessary resources.). Equation 1 drives equations for the predictions of the in-service costs, which are monetary value of the resources used for the execution of operation, maintenance and support tasks.

Mirce-mechanics principles described in the paper are a part of the current design processes at Finmeccanica Airborne & Space Systems Division, Edinburgh, UK. [4]

5. Summary

Through Mirce-mechanics the RMS community has got a single mathematical equation for predicting the expected work done of the future maintainable systems that simultaneously embraces all three in-service processes, namely operation, maintenance and support. This enables expertise and responsibilities of all RMS specialists to be integrated during the design process and

QUIZ ANSWER

A) Reliability Growth - Duane
B) Weibull
C) Sabermetrics
D) Event series (Point processes)

Sabermetrics is the empirical analysis of baseball, especially baseball statistics that measure in-game activity.

the expected work done to be predicted for each feasible alternative of maintainable system considered and thus compare them in respect to expected whole life cost. It is necessary to stress that all of this became available at the time when all design changes could be made at almost no extra time and cost. Thus, designing an aircraft that will be delivering specified number of flights on time or power station with guaranteed annual delivery of energy became reality due to Mirce-mechanics principles and methods. ●

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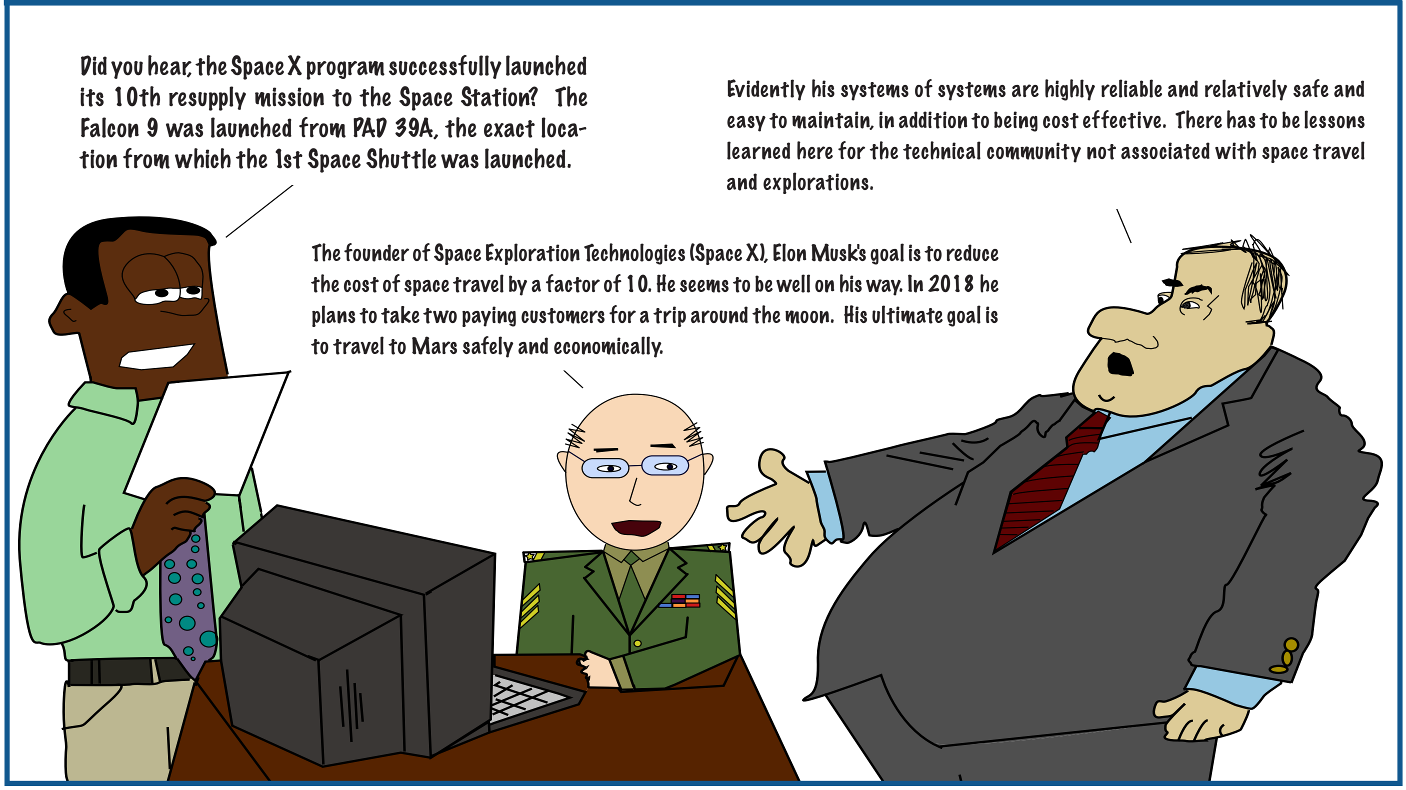
Another Day At The Office

by Russell A. Vacante, Ph.D.



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Joffrey Smitham

Maintainability: Back to Basics

1. Introduction

Originally, maintainability was considered as the 'ability to maintain', and as a consequence, concentrated on rationalizing and simplifying maintenance activities. Nowadays the maintainability engineer has to have a much wider appreciation than the narrow view held several years ago. A maintainability engineer has to have an understanding of reliability, supportability, cost implications and system engineering in order to provide effective and efficient maintainability solutions. Close association with all these disciplines is necessary. This article examines the current definition of maintainability and explains these wider implications.

2. Concepts of Maintainability

The maintainability of an item (as defined within IEC 60050-192 - International Electrotechnical Vocabulary—Part 192—Dependability), is the ability of the item to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance.

"Retained in" is an important concept as maintainability during operation or planned maintenance periods maximises operational efficiency, thereby reducing operational costs.

Maintainability is therefore concerned with:

1) the timing when a maintenance activity should take place;
2) the integration of all maintenance activities for all items within a system (or multi-system) as well as the number of systems in operation;
3) the ease and economy of undertaking maintenance actions.

2.1 Timing

The timing of maintenance actions can be categorised into five elements:

1) *When a system is operational.* The system operation could be fully or partially degraded (there are occasions when a system is not required to operate at maximum performance levels). This is an important concept which is usually considered as a reliability issue, but maintainability and supportability are key drivers.
2) *When a system is on standby.* If the periods of standby are clearly defined, then during these periods, some maintenance could be implemented;
3) *When a system is idle.* A good example is a car where the User drives it to work, it is picked up from the car park, serviced and returned to the car park in time for the User to drive home;
4) *When a system is undergoing a planned maintenance activity* (this could be small levels of maintenance as well as major overhauls). Maintainability analysis could identify some testing and repairs being engineered to occur without extending the planned maintenance time period. In addition,

planned maintenance has to be considered as a collective activity. For example, aircraft engine overhaul needs to coincide with landing gear overhaul in order to minimise out-of-service time (Landing gear overhaul does not have to be the same as the engine overhaul, but every alternate overhaul, say). Similarly, design effort to increase engine overhaul time may provide small benefit if the landing gear overhaul no longer coincides with the engine overhaul time.

5) *When a system has failed during operation.* This is the usual concept of unplanned maintenance. Personally, I consider this term a misnomer as all maintenance is planned—it is the system failing to operate that is unplanned.

2.2 Integration of Maintenance Activities

Examples of integration activities are: the unification of test equipment involved in the testing of the complete system, sub-system and associated items to localise faults and to functionally check out the items and system; the use of similar equipment, tools, and consumables for all item activities; the provision of consistent calibration activities; and standardised approaches to reduce human error.

2.3 Ease of Maintenance Maintenance

The ease of maintenance can involve diagnostic tools, accessibility, simulation, human factors, procedures and diagrams.

3. When to Implement Maintainablity

Maintainability needs to be introduced as early as possible in the initiation of an item to maximise the benefits that can be achieved. These benefits primarily relate to life cycle costs, operational effectiveness and availability. Although the main impact of maintainability is during the Concept and Design life cycle stages, the selection process to procure off the shelf items post manufacture requires a full understanding of these three criteria (life cycle costs, operational effectiveness and availability) if the best items are to be procured. It is also important when selecting an asset already manufactured that consideration should not just be given to the individual asset, but also to the integration activities of maintenance and supportability for the item and associated equipment to minimise overall costs across all the assets.

Maintainability as well as supportability is applicable to repairable items, but the decision to produce/procure a non-repairable item requires maintainability and supportability considerations to be taken into account. Similarly, there are occasions where an item is non-repairable during certain circumstances, but subsequently repairable (such as an item that is non-repairable at sea, but repairable during a major re-fit). In all these cases, the benefits of maintainability and supportability should be considered.

4. The Benefits and Impacts

An effective and efficient maintainability programme can help to minimise the costs involved in developing and producing a product. It can assist in the minimisation of through life costs. A maintenance system overview can help with the cost effective re-design and replacement of items which can no longer be produced due to obsolescence.

Poor maintainability can result in items not being operational when required and/or repairs becoming prohibitively expensive. This can result in a loss in customer confidence for a particular product and can escalate into a loss of confidence in the company. This will impact future orders and it may take a considerable time to restore this loss in confidence.

5. Specific Maintainability Activities

Maintainability is concerned with five main activities and these are listed below to clarify the activities associated with maintainability as opposed to supportability:

1) diagnostic testing to quickly identifying the item requiring replacement (the term replacement in this case includes repair);
2) removing the item (this should not just be removal of the item from a subsystem if removal of the subsystem has to take place as well);
3) replacing the item including re-assembly of any parts of the system;
4) testing the system is operable;
5) releasing the system;

For these activities to operate smoothly, the maintainability engineer must also include aspects of:

1) condition monitoring;
2) testability;
3) inspection;
4) cleaning, lubrication, adjustment, calibration, consumables;
5) preparing and maintaining instructions which detail the test and diagnostic procedures, the methods of removal and replacement including all the equipment, tools and consumables involved;
6) maintainer training and proficiency requirements;
7) manufacturing easements which may reduce manufacturing costs but may be to the detriment of maintainability;
8) maintenance requirements for support equipment that are needed to maintain the system.

Indirectly associated with the above are a number of other factors such as integrated logistic support, obsolescence management, spare parts provisioning, statistical methods in maintainability evaluation, and the verification, collection, analysis and presentation of data.

A maintainability programme

containing a series of tasks needs to be implemented to establish an effective approach. Further detail on these tasks can be found in:

IEC 60706-2 Maintainability requirements and studies during the design and development phase

IEC 60706-5 Testability and Diagnostic testing

6. Maintainability Objectives

A primary objective is to minimise a system's time to repair and this is sometimes found in contractual requirements which specify the mean and 95th percentile values. In some cases an availability is defined (see below) whilst for others, the values are broken down to the individual timing elements mentioned above.

The secondary objective is to minimise through life costs (reliability and supportability are also key role players). In the development of an evolutionary system, for example, a 10% reduction may be requested.

Maintainability planning needs to adopt a flexible approach regarding the type of maintenance as this may change over time. Maintenance can be by the manufacturer, by the user, or by third part maintainers nominated by the manufacturer or user.

It should be noted that these objectives also apply to systems operated within the service industry.

7. Maintainability and Availability

Availability is defined (within IEC 60050-192 - International Electrotechnical Vocabulary–Part 192–Dependability) as the ability to be in a state to perform as and when required.
This can be expressed as:

Availability = Uptime / Total Time

or

Availability = Uptime/ (Uptime + Downtime)

From a maintainability perspective, the contractual requirement of the availability definition is key to establishing the repair times for particular items that have a significant impact upon performance. Other replacements, such as during operation, are not included, but could be costly and may have significant impact if ignored.

7.1 Uptime

Uptime can include one or more of the five timing elements mentioned above. Usually uptime includes timing element v) and occasionally iv).

A further difficulty is understanding the significance of the failure and deciding if the failure has an impact on Uptime. For example the failure of a cigarette lighter in a car may not necessarily be considered as significant for system availability.

7.2 Downtime

Downtime can include logistic delay times, technical delay times, as well as the maintenance activities mentioned above.

7.3 Availability Calculations

With the complexities in uptime and downtime mentioned above, availability has to be carefully defined and this usually requires all possible down time occurrences to be assessed and determined as being either within the calculation or excluded from the calculation. Further reading is available within IEC 61070 - Compliance test procedures for steady-state availability.

8. Summary

I hope this article has helped to emphasise that a maintainability engineer has a wide brief and has to be proactively involved in a number of associated disciplines if the maximisation of performance and minimisation of through life costs is to be realised. I have avoided going into the detail of individual tasks and the associated risks. If further reading is required, there are many books and standards (see the website www.tc56.iec.ch) that can be accessed. ●

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Editorial, from page 1

Falcon 9 and Dragon lift off from Launch Pad 39A for CRS-10 (Courtesy of Space X)

reliability requirements are now serving as a guide for most technical professionals within the general reliability community.

In terms of human travel into space the government funded Space Shuttle was probably the one that most of the general populous could easily identify. The first mission was launched in April 1981 and its last launch was 30 years later on February 24, 2011. Its primary mission was to supply the International Space Station with supplies. Despite some early set backs that resulted in the loss of life (Challenger 1986 and Columbia 2003), the shuttle proved to be highly reliable. It made the round trip from earth to the International Space Station 53 times. The Space Shuttle, from a reliability perspective, set the technical standards for all subsequent space flights.

The launch of Falcon 9 by Space X, also referred to as Commercial Resupply Service (CRS)-10, marks the 10th successful commercial delivery of supplies to the Space Station. The fact that Falcon 9 was launched from PAD 39A—the same location of past Space Shuttle launches—at the Kennedy Space Center is indicative of a lasting legacy.

The above discussion of space missions is informative in that it helps to verify that highly reliable systems of systems are being developed and produced. Further, it confirms that the knowledge, technology and expertise in the field of reliability is available for transfer to our transportation, medical, defense systems and communities. Just as significant is the fact that through commercialization of space efforts we are gaining insight into how to ensure the design and use of highly reliable systems of systems can be accomplished in a cost effective manner. While the U.S. government has provided the initial research dollars, technical environment, scientific expertise and risk for space exploration, the private sector has now stepped up to the proverbial plate to properly scale highly reliable systems of systems in a cost effective manner.

We seem to have come full circle with respect to the learning curve for developing and producing highly reliable systems—at least within the space community. Other communities, regardless of of disciplines, should spend some time with the Space X team to learn their procedures and processes for building highly reliable, safe, easy to use and cost effective systems of systems. We should be inquiring, for instance, whether the private sector space community is doing something different related to reliability tasks than for example, the defense industry. Are the Space X folks conducting, for instance, reliability growth curve programs, FEMCA, qualification testing and parts screening the same as we are or are they doing something different? During our investigation pertaining to the Space X reliability program, we might also discover new and innovative procedures and technologies that can be applied to systems of systems unrelated to the space program. For example, Elon Musk, the founder of Space Exploration Technologies (Space X), has a goal to reduce the cost of human space travel by a factor of 10. Since he seems well on his way to achieving this goal (ultimately

Falcon 9 First Stage Land Landing (ORBCOMM 2 MISSION), Decmber 2015 (Courtesy of Space X)

to Mars) should not the defense and commercial sector capture the lessons-learned from his progress? Or will this be intellectual property not shared with other competitors? Let's be cognitive of the fact that Elon Musk did not invest $100 million of his own money in the Space X project to his financial detriment.

The final challenge for the current, non-space, reliability community is to convince upper management of the benefits of involvement and support. The technical community has long understood that it takes a firm decision from upper management to make reliability requirements a priority. Much of upper management's opposition to achieving optimal reliability for systems of systems has been due to the misplaced perception that achieving high reliability cuts into a company's profits. However, Elon Musk's successful decision-making serves as an upper management role model to improve the reliability of major systems of systems.

In the context discussed above, space truly is frontier from which to explore "strange new worlds" and discover new ways to achieve optimal reliability. ●

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If you are interested in sharing your knowledge in future editions, please contact Russ Vacante at:

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About the Authors

Dr. Jezdimir Knezevic *is a world class researcher, educator and entrepreneur. Over 400 publications disseminated worldwide through books, papers, monographs and reports are attributed to his name. In addition, he has delivered numerous technical presentations, keynote addresses and speeches; in addition, he has been congress, conference, symposium chairman, track leader, workshop presenter, round table moderator on many hundreds of international events which took part in all six continents in over 40 countries. He has been elected as a Fellow, Member or Official of many leading Professional Societies and Institutions worldwide, and has been actively involved in editorial work with the world's leading and prestigious refereed journals and publishing houses. Dr Knezevic has received several international awards for his contributions to research and education. Encouraged by the excellent response from industry to his research and educational activities, in 1988 Dr Knezevic established a self-financing Centre for Management of Industrial Reliability, Cost and Effectiveness, M.I.R.C.E., at Exeter University, UK. Under his leadership, the Centre has attracted over 3000 professional engineers and managers to training and educational Programmes generating an income over 3 million US dollars. In 1999 Dr Knezevic formulated the concept of Mirce-mechanics, the body of knowledge for prediction of the functionability performance of maintainable systems type. To fully focus on the further development, dissemination and applications he resigned from the Exeter University and established the MIRCE Akademy, at the Woodbury Park, Exeter, UK. Under his leadership, the Akademy has educated thousands of professionals coming from Industry, Government and Military Organisations world-wide. Some of them have received internationally recognised Master or Doctoral Diplomas in Mirce-mechanics. Dr Knezevic holds Bachelor, Master and Doctoral degrees from Faculty of Mechanical Engineering, University of Belgrade, Yugoslavia. He shares life with Lynn, is passionate about motorsports, is challenged by the restoration of rusty, but beautiful Lancia rally cars, and enjoys living in a XVI century built thatched cottage in the tranquil village of Bickleigh, Devon, England.*

Joffrey Smitham *C.Phys., CEng., has worked in a number of industries: military and civil aircraft, guided missiles, torpedoes, ships, submarines and computer systems. His work has varied from electrical engineer, metallurgist, design authority, software engineer, project manager, systems engineer as well as managing and practicing RMS. He is currently retired, but is still an active member of the International Electrotechnical Commission, Technical Committee 56 – Dependability.*