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GROUP REPLACEMENT AS MANAGEMENT ACTION IN MIRCE SCIENCE

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Abstract

The core principle of MIRCE Science revolves around the idea that the purpose of any working system is to perform work. The work is accomplished when a specific measurable function is carried out over time. All working systems require maintenance throughout their lifespan. It is generally understood that, during maintenance, the system is not actively performing any work. The duration and frequency of these tasks directly influence the amount of work lost due to maintenance. That work loss is known to have various consequences, such as monetary, reputational, or social implications. The main objective of this paper is to present how a proactive management approach, known as group replacement, can enhance work productivity compared to individual replacements. Under this strategy, the entire group must be replaced when any item within that group fails. This approach aims to minimize the number of maintenance tasks required and maximize the amount of work accomplished. The provided numerical example demonstrates the practical application of MIRCE Science in quantitatively evaluating the impact of group replacement on work productivity and resource allocation.

Keywords: *MIRCE Science, working systems, group replacements, maintenance management actions, MIRCE Functionability Equation, work done*

1 INTRODUCTION

The philosophy of MIRCE Science is based on the premise that the purpose of the existence of any working system is to do work. The work is done when the expected measurable function is performed through time. MIRCE Science focuses on the scientific understanding and description of the physical phenomena and human rules that govern the motion of working systems through MIRCE Space. An understanding of the mechanisms that generate this motion is essential for the accurate predictions of the expected work done by a given working system type using the mathematical scheme of MIRCE Science (Knezevic, 2017).

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That all working systems require some maintenance during their lives is generally accepted. The process during which the ability of a working system is retained or restored consists of a set of well-defined maintenance tasks. For these tasks' execution, resources like spares, materials, trained personnel, tools, equipment, maintenance manuals, facilities, software, and similar are needed (Knezevic, 1997). It is also commonly accepted that working systems do not do their job during maintenance operations because the expected functions are not performed. Thus, the amount of work lost due to maintenance is directly proportional to the duration of the maintenance tasks, the frequency of their demands, and the number of resources available. It is also commonly accepted that the amount of work lost has monetary, reputational, or social consequences.

In summary, the main objective of this paper is to expose the management community to the potential benefits of group replacement maintenance. Each management action impacts the functionability performance of working systems, like work done, resources consumed, lost revenue, profit generated, and so forth (Knezevic, 2016).

A numerical example presented in this paper illustrates the practical application of MIRCE Science to the quantitative prediction of the potential benefit of group replacement maintenance policy concerning the commonly applied maintenance practices.

2 MIRCE SCIENCE FUNDAMENTALS

According to MIRCE Science, at any instant of calendar time, a given in-service system could be in one of the following two macro states (Knezevic, 2017):

- Positive Functionability State (PFS - a generic name for a state in which a working system can deliver the expected measurable function(s)),
- Negative Functionability State (NFS - a generic name for a state in which a working system is unable to deliver the expected measurable function(s), resulting from any reason whatsoever).

In MIRCE Science, work done by a working system is uniquely defined by the trajectory generated by its motion through the MIRCE Space[1]. That motion is driven by functionability actions, which are classified as:

- Negative Functionability Action (NFA - a generic name for any activity whatsoever that compels a system to move to an NFS).
- Positive Functionability Action (PFA - a generic name for any activity whatsoever that compels a system to move to a PFS).

The time evolution of a working system through MIRCE Space is physically manifested through the occurrences of functionability events, which are classified as:

- Positive Functionability Event (PFE - a generic name for any physically observable occurrence at which a working system moves from an NFS to a PFS),
- Negative Functionability Event (NFE - a generic name for any physically observable occurrence at which a working system moves from a PFS to an NFS).

To scientifically understand the mechanisms that generate functionability actions, positive and negative, analysis of the in-service behavior of several thousands of items, modules, and assemblies of in-service systems in defense, aerospace, nuclear, transportation, motorsport, communication, and other industries have been conducted at the MIRCE Akademy.

2.1 MIRCE Functionability Equation

This multidimensional set of convolution integrals defines the motion of a working system through MIRCE Space, depicting and passing through each sequential functionability state in the direction of calendar time, generating a trajectory unique to each working system. Thus, the same set of generic equations, when applied to different operational and maintenance management actions generate different trajectories of the motion through the MIRCE Space, which means different functionability performances, namely different work done, and different resources consumed. Hence, Knezevic (2017) has created a generic platform on which each feasible set of operation and maintenance management actions would generate its own future "trajectory" for a working system under consideration.

[1] MIRCE Space is a conceptual 3-dimensional coordinate system depicting a probabilistic trajectory of the motion of a working system through the MIRCE functionability field. (Knezevic, 2017)

According to MIRCE Science, a working system delivers expected work while it is PFS. According to Knezevic (2017) the probability of the working system being in PFS, at any instant of its in-service life, is determined by MIRCE Functionability Equation, $y_S(t)$ defined as (Knezevic, 2014):

$$y(t) = 1 - \sum_{i=1}^{\infty} F_S^i(t) + \sum_{i=1}^{\infty} O_S^i(t) \qquad (1)$$

In equation 1, $F_S^i(t)$ is a negative functionability function. Mathematically, it is a cumulative distribution function of the random variable that represents the time to the occurrence of the i^th^ negative functionability event, $TNE_S^i(t)$ of a working system considered. In MIRCE Science it is defined by the following convolution integral:

$$F_S^i(t) = \int_0^t O_S^{i-1}(x) dF_{S,i}(t-x), \qquad i = 1, \infty \qquad (2)$$

where: $F_{S,i}(t)$ is a cumulative distribution function of the random variable that mathematically represents the time to the occurrence of the i~th~ negative functionability event, $TNE_{S,i}(t)$ of a system considered.

In Eq. 1, $O_S^i(t)$ is a positive functionability function. Mathematically, it is a cumulative distribution function of the random variable that represents the time to the occurrence of the i^th^ positive functionability event, $TPE_S^i(t)$ of a system considered. In MIRCE Science it is defined by the following convolution integral:

$$O_S^i(t) = \int_0^t F_S^i(x) dO_{S,i}(t-x), \qquad i = 1, \infty \qquad (3)$$

where: $O_{S,i}(t)$ is a cumulative distribution function of the random variable that mathematically represents the time to the occurrence of the i~th~ positive functionability event, $TPE_{S,i}(t)$ of a system or item considered.

In summary, it is essential to stress that the above-presented equations are generic mathematical interpretations of the physical reality of the motion of working systems through MIRCE Space, resulting from any functionability actions whatsoever and the actions required to generate any functionability motion. However, the accuracy of their predictions is in the hands of their users, whose knowledge and understanding of the physical reality guide them to the selection of the most appropriate mathematical functions to represent the impacting natural and human actions.

2.2 Work done by working system in MIRCE Science

According to Knezevic (2017) the expected positive work to be done by a working system during a given interval of calendar time *T*, *PFW~S~(T)*, measured in calendar hours, Hr, can be predicted by making use of the following equation:

$$PFW_S(T) = \int_0^T y_S(t) dt \qquad [Hr] \qquad (4)$$

The expected negative work to be done by a working system during a given interval of calendar time *T*, *NFW~S~(T)*, measured in calendar hours, Hr, can be predicted by making use of the following equation:

$$NFW_S(T) = \int_0^T n_S(t) dt \qquad [Hr] \qquad (5)$$

where: $n_S(t)$ is a function in MIRCE Science that defines the probability of a working system being in NFS at any instant of in-service time t.

3 THE RATIONALE FOR GROUP REPLACEMENT MANAGEMENT ACTIONS

Individual replacement is a management action approach where each item in a working system is replaced after its failure, which means that it is fully utilized.

Group replacement is a management action where all individual items within a group designated are replaced after the failure of any of them. This practically means that replacement tasks of individual items from the group start at the same instance of time and are performed simultaneously. The group replacement task is completed when all the consistent replacements have been completed.

3.1 Group Replacement Strategy as Design Action

Group replacements of some items are often requested by the designers of functional systems. The most common reasons for group replacements are:

- Safety considerations of the working systems for users and the environment
- Technological constraints or limitations of the system.

For example, the replacement of all discs' pads, spark plugs, engine valves, and so forth in motor vehicles is requested when any one of them reaches its failed state.

Typically, group replacement's design actions are incorporated in their maintenance manuals and are a part of the warranty conditions, and as such they cannot be altered by in-service management actions.

3.2 Group Replacement Strategy as Management Action

To reduce work lost it is also possible to undertake group replacement of heterogeneous items so that when anyone fails, replacement of all the items from the designated group takes place. As the number of items in a replacement group, *nigr*, increases the number of group replacements decreases because the total number of NFEs decreases. However, the cost of spare parts for each group replacement will increase because all the items will not be used to the full. At the same time, the total duration of group maintenance tasks would be shorter than the total time for the equivalent work for the individual replacements, as the working system is already in a maintenance state. Hence, there must be an optimal management decision between these two competing alternatives, which would deliver the minimum work lost for the resources available.

A typical example of a group replacement task is the pit stop of a racing car, where tyre replacement, fuel refilling, and windscreen cleaning are performed simultaneously. This situation requires more maintenance resources and complex logistics, but it minimizes the consequential work lost. Hence, the replacements are performed simultaneously and the whole task is finished when all the consisting tasks are completed by the corresponding specialist members of the team or teams involved.

4 PLACING GROUP REPLACEMENT IN THE MIRCE FUNCTIONABILITY EQUATION

To assess the impact of group replacement, as a feasible management action, it is necessary to place it in the MIRCE Functionability Equation, defined by Eq. 1.

4.1 Negative functionability function for group replacement

The negative functionability function $F_{S,i,gr}(t)$ for the group replacement maintenance action, as a possible management action, is defined by the probability distribution of the random variable $TNE_{S,i,gr}$, and it is defined by the following expression:

$$F_{S,i,gr}(t) = P(TNE_{S,i,gr} \le t) = 1 - \prod_{j=1}^{nigr}\left[1 - F_j(t)\right] \qquad (6)$$

where: $F_j(t)$ is a cumulative distribution function of the *TNE* of the j-th item within the group, driven by its negative functionability action. Thus, the above expression represents a probability that an NFE_{gr}, for the group of items, will take place before or at the instant of time t.

4.2 Positive functionability function for group replacement

The positive functionability function $O_{S,i.gr}(t)$ for the group replacement maintenance action, as a possible management action, is defined by the probability distribution of the random variable $TPE_{S,i,gr}$, and it is defined by the following expression:

$$O_{S,i,gr}(t) = P(TPE_{S,i,gr} \le t) = \prod_{j=1}^{nigr} O_j(t) \qquad (7)$$

where: $O_j(t)$ is a cumulative distribution function of the *TPE* of the j-th item within the group, driven by its positive functionability action. Thus, the above expression represents a probability that a *PFE_{gr}*, for the group of items, will take place before or at the instant of time t.

5 ILLUSTRATIVE EXAMPLE

To illustrate the applicability and practicality of the methodology proposed, a hypothetical example is used.

5.1 Management action challenge

The working system under consideration consists of three maintenance significant items, namely item-1, item-2, and item-3. The data related to the time of the occurrence of an NFE for items considered are given in Table 1.

Table 1: Time to NFE of maintenance significant items of the system considered.

Item	Distribution	Parameters		Unit
Item-1	Normal	60	12.0	Week
Item-2	Normal	80	16.5	Week
Item-3	Weibull	104	3.1	Week

Although the data presented in Table 1 are hypothetical it is necessary to stress that they could realistically represent the physical mechanism that generates occurrences of NFEs for the three items considered as they have time-dependent hazard functions, Knezevic (1993).

The impact of NFA on each item could be fully rectified by its replacement. The necessary data regarding that task stated are presented in Table 2.

Table 2: Time to PFE of maintenance significant items of the system considered.

Replacement Task	Distribution	Parameters		Units
Item 1	Normal	25	3	Day
Item 2	Weibull	39	4.2	Day
Item 3	Normal	55	5	Day

The management challenge highlighted in this example is the determination of the management action that will deliver the maximum possible output of the working system which is expected to be in operation for 5 years. The system operates in three shifts, seven days a week, which practically means that operational and maintenance resources are available all the time.

In summary, will the individual replacement of each failed item be the management action that will generate the highest output measured in working hours, or should the group replacement be a better management action?

5.2 Management action solution

The task of this example is to determine the amount of time that a working system will spend in PFS while continuously delivering expected functionability during 5 years of operation.

Making use of the data provided above, the negative functionability functions for the items considered are as follows:

- for Item-1: $F_{1,j}(t) = \int_0^t \frac{1}{12.0\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{t-60}{12.0}\right)^2\right] dt = \Phi\left(\frac{t-60}{12.0}\right), \quad j = 1, \infty$
- for Item-2: $F_{2,j}(t) = \int_0^t \frac{1}{16.5\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{t-80}{16.5}\right)^2\right] dt = \Phi\left(\frac{t-80}{16.5}\right), \quad j = 1, \infty$
- for Item-3: $F_{3,j}(t) = 1 - \exp\left[-\left(\frac{t}{104}\right)^{3.1}\right], \quad j = 1, \infty$

where: Φ is the standard normal distribution function ($\mu = 0, \ \sigma = 1$), numerical values of which could be found in statistical tables for Normal distribution.

The negative functionability functions for the group replacement of all three items, upon a failure of any of them, $F_{S,j,gr}(t)$ are defined by Eq. 6, thus:

$$F_{S,j,gr}(t) = 1 - \left[1 - \Phi\left(\frac{t-60}{12.0}\right)\right] \times \left[1 - \Phi\left(\frac{t-80}{16.5}\right)\right] \times \left\{-\exp\left[-\left(\frac{t}{104}\right)^{3.1}\right]\right\}, \quad j = 1, \infty$$

Corresponding expressions for the time to the occurrence of PFE, due to the replacement of each item are given below, for the data from Table 2, thus:

- for Item-1: $O_{1,j}(t) = \int_0^t \frac{1}{3\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{t-25}{3}\right)^2\right] dt = \Phi\left(\frac{t-25}{3}\right), \quad j = 1, \infty$

- for Item-2: $O_{2,j}(t) = 1 - \exp\left[-\left(\frac{t}{39}\right)^{4.2}\right], \quad j = 1, \infty$

- for Item-3: $O_{3,j}(t) = \int_0^t \frac{1}{5\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{t-55}{5}\right)^2\right] dt = \Phi\left(\frac{t-55}{5}\right), \quad j = 1, \infty$

The positive functionability functions for the group replacement of all three items, upon a failure of any of them, $O_{S,j,gr}(t)$ are defined by expression (7), thus:

$$O_{S,j,gr}(t) = \Phi\left(\frac{t-25}{3}\right) \times \left\{1 - \exp\left[-\left(\frac{t}{39}\right)^{4.2}\right]\right\} \times \Phi\left(\frac{t-55}{5}\right), \quad j = 1, \infty$$

Dubi (2002) the possibility of finding an analytical solution for multidimensional convolution integrals defined by Eq. 2 and 3 is seldom possible due to the inability of mathematics to deal with the large number of convolution functions and their interactions. These types of problems are not specifically related to MIRCE Science, they are common to all scientific disciplines of this nature, as it is a known mathematical fact that integral equations do not have analytical solutions.

The most suitable way forward, according to Knezevic (2017), for any real working system, of any complexity of operational reality, is to apply the Monte Carlo method as the only viable approach with which solutions for the MIRCE Functionability Equation and thereby the system performance may be obtained. It is applicable to systems with multiple interacting components, aging mechanisms, and any operation, maintenance, and support rules.

The final solution to the management challenge considered is obtained by the Monte Carlo method application as the only feasible solution for obtaining a quantitative answer to the MIRCE Functionability Equation. The results obtained are presented in Table 3. Group replacement is the preferential management decision for the challenge considered.

Table 3: Quantitative solutions for the management actions considered.

	Management action		
Failed item replacements	Individual	Group	Units
Expected PFW (260 weeks)	218.09	230.21	Week
	1,526.63	1,611.47	Day
	36,639.12	38,675.28	Hour
Effectiveness	0.83	0.88	n/a

It is necessary to stress that the quantitative and monetary values between the two management actions have not been addressed in this example. However, it is easy to see the recommended action applicable to all the cases where the value of extra resources is less than the value of the 2036 additional hours the working system considered will be in PFS doing the expected work.

6 CONCLUSION

The main objective of this paper is to show how group replacement could be used as a proactive management action for increasing the work done by working systems concerning individual replacements of failed items.

The philosophy of MIRCE Science is based on the premise that the purpose of the existence of any working system is to do work. The work is considered completed when the expected measurable function is performed through time. However, it is commonly accepted that all working systems require maintenance during their lives. It is also commonly accepted that while required maintenance tasks are performed, working systems do not work. Thus, the amount of work lost due to maintenance is directly proportional to the duration of maintenance tasks and the frequency of their demands. It is also commonly accepted that the amount of work lost has monetary, reputational, or social consequences.

Group replacement is a management action where all individual items within a designated group are replaced after the failure of any of them. This practically means that replacement tasks of individual items from the group start at the same instance of time and are performed simultaneously. The group swap task is complete when all swaps are done.

A numerical example is presented to illustrate the practical application of MIRCE Science for the quantitative assessment of the impact of the group replacement on work done and resources committed by applying this management action. At the same time, the numerical example presented shows mathematical difficulties in finding quantitative solutions to multi-dimensional convolution integrals, which must be used to realistically represent the motion of a working system through functionality states concerning time. That is the only way to make accurate predictions of the expected functionality performances of designed and managed functional systems.

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