Index for asset value measure obtained from condition monitoring digitalized data interpretation. A railway asset management application

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Abstract

The objective of any asset is to provide value to the organization, being the corner stone to get a highest possible economic benefit in a sustainable way. An effective asset value management demands method that allow measuring and comparing the expected value with the real value realized at any time during its life cycle for value informed decision-making. Digitalization is providing new data about events and states related to asset condition and risk, information that can be reinterpreted to generate value measure strategies. This paper presents a proposal of TVO (Total Value of Ownership) model where it is possible to quantify and measure the value, including its monitoring throughout the life cycle of the asset and/or system.

Proposed TVO model is focused on Safety, one of the most relevant value factors for Industry and Infrastructure sectors. Asset events and states are intrinsically linked to the defined failure modes. Consequently, it is necessary to structure the system information around the failure modes that have been defined, in order to obtain a value measurement index. A railway use case is presented.

Keywords: TVO, Condition Monitoring, Value Based management

1. Introduction

The aim of this paper is to present a case of a quantitative asset management tool consisting of obtaining a value measurement index. The index proposal and its use are linked to the use of TVO models to support decision making in the central phase of the life cycle of an asset or MoL (Middle of Life) (Roda et al., 2015). These models are connected to the best known TCO models. TVO proposes and emphasizes management by value, in accordance with the postulates of the ISO 55000 standard, as opposed to an exclusive management based on the economic costs of the TCO. The application of TCO in the industry and other sectors is mature while the TVO models are much scarcer and there is not enough consensus either on their design, calculation or their application in decision making (Srinivasan and Parlikad, 2017). This paper tries to make a contribution in this sense.

At the same time, digitization makes new capabilities available to organizations. It highlights, in a significant way, the possibility of developing new models of data and information not available until now. In particular, this digitization allows the development of new uses of data extracted from a monitoring system. This study proposes the connection of monitoring with the calculation of an index to measure the value that is reliable to the organization, on which to make decisions and control the outcome of them in the medium and long term.

The paper is structured as follows: the following section briefly reviews the key aspects and concepts about the developments of this work. Section 3 presents the methodology used to obtain the value index related to safety; Section 4 briefly presents a practical case that has served as support for the development of the model. Finally, Section 5 includes the main conclusions of this work.

2. Background

"Value" is one of the key concepts in asset management (Roda et al., 2015). The international standard ISO 55000 (ISO, 2015) establishes that asset management promotes the contribution of value, and defines the asset as the element that has or generates value for the organization. Asset management should be conducted around value control. To this end, each asset has to be managed and defined according to the concept of the organisation’s own value that it itself establishes (Sola et al. 2015). The definition of the value of each organization makes it possible to define which are those assets and in what way they contribute to obtaining the expected value or its conservation (IAM 2010). However, there are currently not many management tools that integrate the concept of value, and in most cases economic indicators are used as the basis for decision-making. Therefore, it is necessary to deepen in the development of new indicators and methodologies that allow the objective measurement of value in order to be able to manage the assets around this concept in an efficient and effective way (Gonzalez-Prida et al., 2019).

The Total Cost of Ownership (TCO) is the sum of all costs incurred by the owner of a physical asset throughout its entire life cycle (Ellram, 1995). These costs are those required to acquire, install, commission, operate, maintain and finally dismantle the equipment (Duran et al., 2016). All these costs play an important role in the decision-making process, especially in aspects such as maintenance planning, spare parts purchasing and operating strategies among others. In addition, it has been proven that the TCO can serve as a support tool for management, obtaining a measurement and reduction of costs (Bacchetti et al., 2018). The TCO is a cumulative cost index as it includes all the costs associated with the life cycle of an asset. It makes it possible to estimate and monitor the cost in its different phases.

The Total Value of Ownership concept extends the TCO approach to the monitoring and control of aspects of value such as social and environmental impact, as well as the economic aspect as offered by the TCO (Srinivasan and Parlikad, 2016). While the TCO only provides information for economic management while the TVO allows a management focused on the value that is promulgated by asset management (ISO, 2015). The management focused on the TVO allows maximizing the operation for a certain budget, while the management focused on the TCO, minimizes the budget to maintain a certain level of operation (Srinivasan and Parlikad, 2017). As a result, the TCO makes it possible to maintain a level of service while the TVO tries to obtain the optimum level of service. The difficulty of implementing a management system based on value versus cost lies in the concepts used, the second are consolidated in the industry while the first are not.

The processing of events/states is the basis for the quantitative indicators that maintenance engineering uses. In fact, the RAMS (Reliability, Availability, Maintainability and Safety) analysis methodology is based on the management of a set of indicators obtained from the evaluation of the characteristic times of the operating and fault states that, in turn, limit the events of failure and repair (Parra and Crespo, 2012). A failure occurs when an asset fails to perform its required function (Birolini, 2017). On the other hand, the term to define the state of inactivity is not the failure, it is the fault (Figure 1). As schematized in Figure 1, repair is an event that returns the asset to the operating state. This same event/state scheme can be used in a more general way to model intermediate states generated from available information through monitoring techniques that give access to detailed knowledge about the asset degradation process until failure.

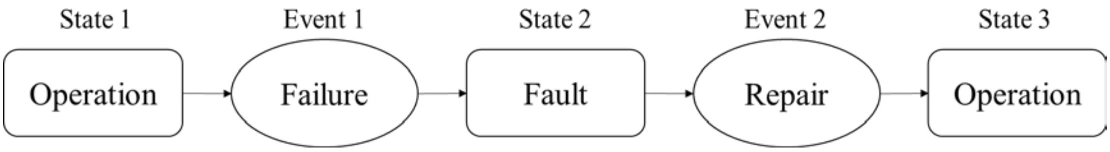

Figure 1. Basic states and events of RAMS analysis methodology.

Condition-based maintenance (CBM) is a monitoring-based maintenance strategy that focuses much of the digitization efforts of maintenance, especially in the development of predictive solutions or PHM (Prognosis and Health Management) (Jardine et al., 2006). Technological development has made it possible to reduce the costs of sensors and systems that measure assets, making it possible to obtain data on assets considered critical. The monitoring and analytical techniques used in the CBM make it possible to control the risk of failure and predict the time to failure or RUL (Remaining Useful Life) (Guillen et al., 2016). Risk is the product of the probability of occurrence of a failure and its consequence (Crespo, 2007). Condition monitoring is linked and allows to control the probability factor. A specific monitoring measure may indicate a higher probability of failure and, therefore, a higher risk. It is the identification of different levels of risk that supports maintenance decision making. These levels are defined from reference values or thresholds.

Similar to what happens with failures and times between failures in the RAMS methodology, the new events and states identified through monitoring and their thresholds allow handling events and intermediate states between operation and fault states. The management of these states and their characteristic times can give rise to new indicators of interest for management. These include objective quantitative measures of value. In this way it is possible to link condition monitoring to value-based decision making.

3. Methodology for the calculation of the TVO

This methodology connects the result of the monitoring to the evaluation of the TVO. It can be understood as part of an information management strategy aimed at generating new information for the digitization of decision-making processes.

It is necessary to establish a structure of information related to the asset in order to make full use of all available data provided by monitoring. Three pillars or fundamentals of description have been taken into account in the modelling of asset-related information:

- Objective definition of value. Generation of value measurement index.
- Failure mode as object of maintenance. Any data is interpreted in relation to the failure mode or the failure modes it affects.
- Events and states of failure modes. The value index measurement itself refers to the failure mode. Events and states appear as a result of monitoring and their interpretation at risk levels for each failure mode. The interpretation of the risk levels translates into a measure of the value index.

The methodology includes the following steps illustrated in Figure 2:

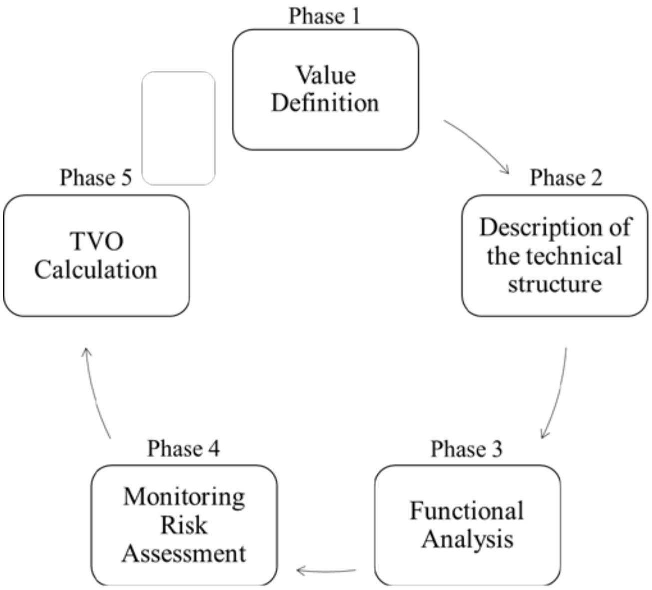

Figure 2. Steps of the proposed methodology.

Phase 1. Value Definition. First of all, it is necessary to define the concept of value according to the objectives and principles of the organization. The organization provides the most important factors related to its activity (e.g. safety, environmental impact, quality of service, etc.). These factors will allow to define the value for that organization, being different in each organization. Each factor can be parameterized in a series of measurable indicators in all assets. The evaluation of the criticality of the assets will be carried out from the defined factors. The definition of the factors has a double functionality: (i) the evaluation of the criticality and hierarchization of assets by value; (ii) the calculation of the TVO. In the practical case, a value measurement index will be generated around the Safety factor, as will be seen later.

Phase 2. Description of the technical structure. The system is broken down into the different levels of intervention that make up its technical structure. The intervention levels try to describe in a precise way the element to maintain within the technical structure. These levels will then make it possible to determine at what level certain maintenance policies are applied. The correct definition of the intervention level conditions all subsequent decisions (López, 2018).

Phase 3. Functional Analysis. It allows to obtain a description of failure modes linked to the general system through the technical structure. The failure mode is the basic element in maintenance management. Each unit performs one or more functions. The failure mode is associated with a maintainable component of an equipment. For each function performed by an equipment, there are as many failure modes as there are maintainable components in the equipment (López 2018).

Phase 4. Monitoring Risk Assessment. The methodology proposes the interpretation of monitoring, generating risk indicators and rules of interpretation on these indicators. It is possible to define different levels of risk through thresholds or reference values, introducing new intermediate states between operation and fault. A risk level is therefore the representation of a state. This begins with the event that a threshold is exceeded and ends when the indicator leaves that level. This level change may be due to a new higher risk threshold being exceeded (progress in degradation) or due to a reduction in the risk level (reduction may be due to maintenance action or spontaneous favourable evolution) (Figure 3). Figure 3 shows that when a critical risk level is reached (corresponds to a critical value), maintenance is carried out to avoid failure and ensure operation.

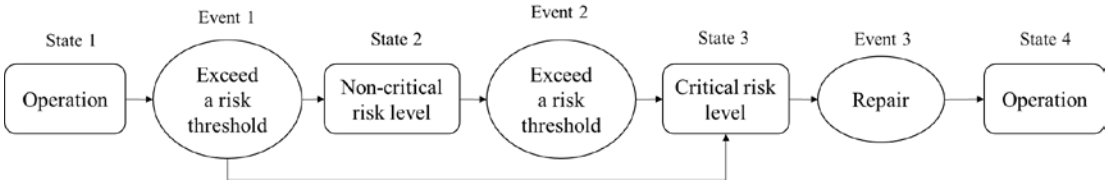

Figure 3. States and events according to methodology.

Phase 5. TVO Calculation. In order to carry out a measurement and a control of the value, the TVO concept will be used. This concept allows to relate the measurement of the value with the life cycle of the asset being of great help for decision making in the medium and long term.

The proposed TVO model focuses on giving a measure of the value factor "Safety", although it would be possible to develop similar indices for any other value factor. The ISG is defined as a quantitative index that measures the total of equivalent days in which an asset or group of assets is at its maximum level of safety considering:

- The maximum safety in an asset (100 % or 1) corresponds, at all times, to the theoretical maximum safety, i.e. the state in which the asset does not present any objective circumstance involving a risk of a significant reduction in safety.
- Each level of risk determined as a result of monitoring is assigned a specific percentage decrease in safety. This interpretation is carried out with the participation of expert personnel in the installation. In this way, depending on the level of risk at which an asset is located, it is possible to know how much safety has been reduced.
- Equivalent days: the safety reduction is computed in days, so that, if during a calendar day of an asset has been at 50% of its maximum safety level, only 0.5 days will be added to the ISG calculation.

The model used for calculating the indicator is shown in the following statement:

$$\sum_i ISG_i\,(\Delta t) = \sum_i \left(DT_i(\Delta t) - \sum_j DSD_{ij} \right) \quad (1)$$

$$DSD_{ij} = DD_{ij} * Cc_i * Css_j \qquad (2)$$

Where:

- i: asset on which the safety fault is identified.
- j: failure mode detected.
- DT_i: total days in the period considered.
- DD_{ij}: estimated days from the beginning of the problem.
- DSD_{ij}: equivalent days of reduced safety.
- Css_j: Severity of the failure by Safety 0-1.
- Cc_i: Criticality coefficient of asset i, 0-1.

As it was being searched for, it is a value measurer. It is related to the value factor Safety, defined during the design of the corresponding asset management model. It is a cumulative index, similar in this sense to the cost that serves as the basis for the TCO models. In this way it is possible to treat the accumulated ISG throughout the life cycle or the ISG during a certain period of time or until a certain date.

4. Use case

In the practical case, the proposed methodology is applied in the railway field, in particular on metro lines. For this purpose, information on a metro line is available. Information is available on the technical structure and parameters associated with the equipment contained therein. On the other hand, information is available on the set of factors in which the organisation has broken down its concept of value, which will allow the criticality of the functional locations to be evaluated.

Between value factors, safety is the most important factor. This makes it possible to focus the study on the measurement of safety, leading to the creation of a total value model based on this factor. This need to generate the model around safety is justified in the following statements:

- In railway systems in general, and in the metro in particular, safety is paramount.
- If safety is diminished or reduced, it does not necessarily mean that a failure or accident occurs.
- On the other hand, what it does imply is that during the safety degraded state, safety is not satisfied to its maximum possible level.
- It has been observed that the non-detection of failures or their non-appearance hide reductions in safety. This mask the results of the evaluation of asset performance and maintenance. In this way, circumstances that may be important for the effective control of risk and safety are not taken into account in decision-making or in proposals for improvement.

In order to carry out the practical case, a system has been generated that allows the management of assets. This system allows the processing of the information transmitted by the on-board monitoring system. Before receiving and processing the information transmitted by the monitoring system, it is necessary to define the first three phases proposed in the methodology. This allows the system to have the necessary premises to carry out the remaining phases.

Phase 1. For the railway case under analysis, a set of value factors has been defined. The factors defined are: safety, social and environmental impact, integrity and life cycle, operation and quality of service and cost of corrective maintenance. Each factor, according to the organisation's criteria, has been assigned a percentage, the sum of these percentages being 100%. The organisation has defined that 40% of safety has been assigned, the main reason for which a safety-centred value measurement index has been developed.

Phase 2. In order to define the technical structure, it was necessary to define the levels of intervention. The intervention level is the one at which the maintenance policies will be applied. At the same time, this precisely determines the object of the analysis. The existing model of the railway track did not provide enough information, and it was necessary to obtain a new model. A total of seven levels of intervention have been defined: line, section, subsection, system, subsystem, equipment and component. In this way, the elements where the maintenance activities are carried out are precisely defined. The sub-section level allows to distinguish curves and slopes with specific operating conditions and degradation modes that can be related to monitoring.

Phase 3. For each of the assets that compose the system, a study has been carried out on the different failure modes that can take place in them. Some of the failure modes that occur on a railway track are illustrated below: cracked track, worn track or dirty track. These failure modes have been defined on the basis of the history of failure modes and the advice of technical experts in railways.

Phase 4. In order to evaluate the risk of failure due to a failure mode in an asset three requirements are necessary: (i) define a set of risk indicators whose thresholds are defined by the value of the monitored parameters (e.g. length of serious defect if the value is greater than 40 mm); (ii) an on-board monitoring system that transmits the information in real time; (iii) use logical rules of interpretation (combination of AND or OR types) of the defined risk indicators to assess the risk in each failure mode (e.g. the risk level is high for the failure mode "Cracked track" if the risk level of the "defect length" indicator is high and the risk level of the "defect width" indicator is medium).

The graph to the left of Figure 4 shows the time evolution of a risk indicator. The colours grey, green, yellow and red are associated with zero, acceptable, medium and high risk levels respectively. It can be observed how for this risk indicator, along the analysed temporal horizon, its risk level increases until a maintenance action is carried out reducing the risk to 0. The graph to the right of Figure 4 shows the duration of each risk level of each failure mode for all assets analysed. The graph shows the duration of the risk levels for the "Dirty track" failure mode of the different assets.

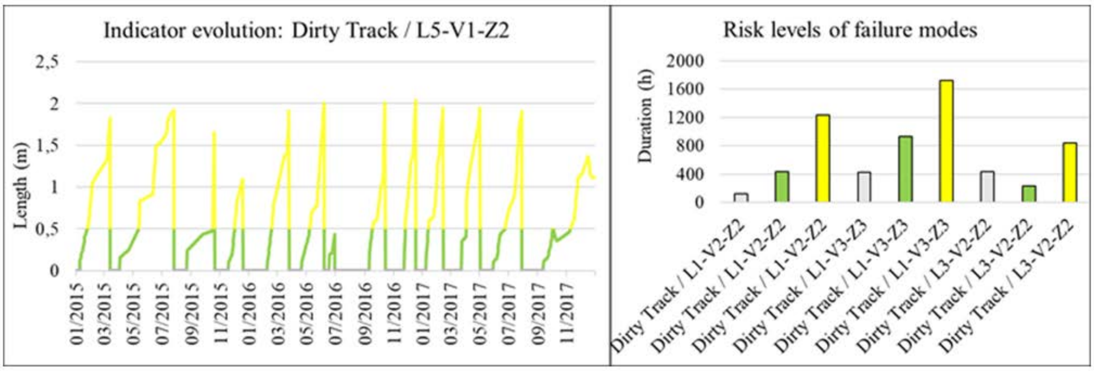

Figure 4. On the left, representation of the evolution of a risk indicator in the analysed time horizon. On the right, the duration of the risk levels of a multi asset failure mode.

Phase 5. The duration of the different levels of risk has a translation that is reflected in the measure of the value index, in this case, of the ISG. Thanks to the on-board monitoring system, a real-time measurement of the value can be obtained. The system is able to draw a graph where the comparison of the real value in real time and the theoretical value of the ISG is carried out. Also, it shows the value of the real TCO against the theoretical one in real time (Figure 5).

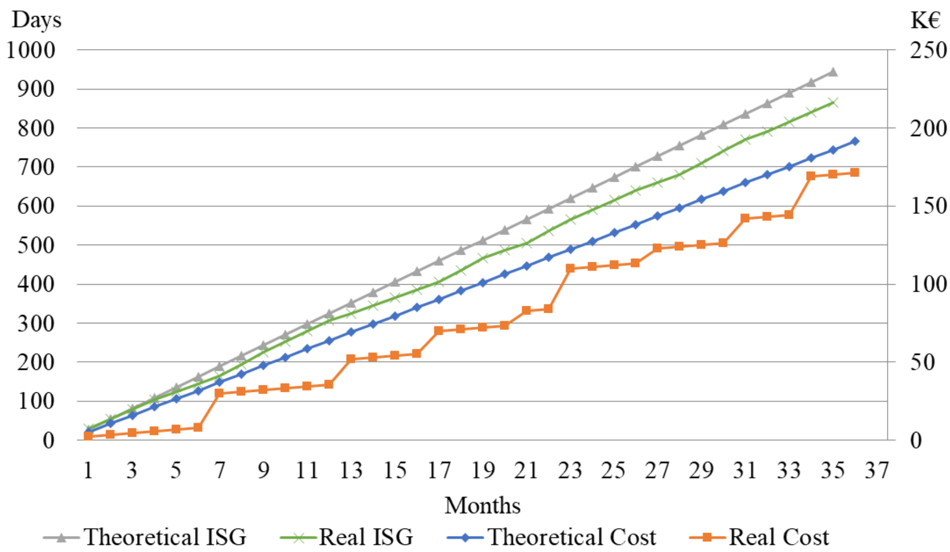

Figure 5. Theoretical and actual ISG and TCO on the analysed time horizon (ISG referred to left axe and TCO referred to right axe).

The decision-making process for carrying out maintenance activities will be conditioned by two interrelated measures: the level of risk of an asset and the value of the asset's ISG.

5. Conclusions

Value is a concept inherent to each organization that depends on its objectives, being difficult to quantify because there is no general procedure for defining it. On the other hand, existing asset management tools and models allow decisions to be made based exclusively on economic value, not on the value of the organization. In order to define value in a clear and concise way, an asset management tool is proposed where information is structured around failure modes and events that take place in the assets. Consequently, an intelligent asset management system has been developed with the mentioned approach, being used in a practical case in the railway field.

Monitoring makes it possible to know the state of the assets and, consequently, to know the level of risk they have at any given moment. The duration of the different risk levels of the assets has a translation in terms of equivalents days of security. The value of the ISG is proportional to the equivalent days of safety. The measure of the value in terms of security can be done through the ISG. By comparing this value measurement with the theoretical value calculated at the beginning of the life cycle of the asset, the operation of the asset can be evaluated and, where appropriate, acted upon. In this way it is possible to link condition monitoring to value-based decision making.

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