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What are the main differences and similarities between TPM and RCM?

Abstract
Purpose: The center of research are the two main maintenance management systems in conceptual terms and enforcement in industrial environments: Total Productive Maintenance - TPM and Reliability Centered Maintenance - RCM. Rise up the main characteristics of each system, and compares the two in order to obtain the main differences and similarities.
Design/methodology/approach: It is about a literature review, which presents the main fundamentals, characteristics and methods inherent to each maintenance system studied. First concepts are developed, then the paper has applications maintenance systems to finally performing the comparison between TPM and RCM.
Findings: We discovered that gaps exist in both the TPM as the SPC, and a hybrid approach between these systems can bring earnings related to these gaps observed. It was noticed also that the process of implementation of maintenance systems largely depends on the manager that implements it, and despite having distinctive characteristics, implementation steps differ by organization.
Research limitations/implications: The TPM and RCM implementation process is not linear in organizations which creates complications to conduct an objective comparative analysis.
Originality/value: The main value of the research is to construct a franmework implementation of TPM and RCM in industrial environments, defining and comparing deployments processes. Not least, the research makes a comparative analysis of both systems, considering: origin, fundamental focus, implementation strategy, team building process, central method of application, work approach, system organization, fundamental objective and primary metric.
Keywords: Maintenance. TPM. RCM. Reliability. Industry Implementation. Systematic Comparison. Productivity. Literature Review.
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I. INTRODUCTION

In the industry, maintenance has a great impact in operational efficiency, prediction, andminimization of damage. Two systems of maintenance management have extensivelybeen highlighted in the literature: TPM (*Total Productive Maintenance*), of Japanese origin, aligned with lean thinking and acting directly on the reduction and elimination of losses; and RCM (*ReliabilityCenteredMaintenance*), which focuses on economic efficiency in decision-making.

TPM is an equipment maintenance system that involves all employees in various areas of the company, especially engineering, maintenance and operation. Its objective is double, aimingto achieve zero failures and zero defects. As a result of eliminatingfailures and defects,we are able to increase equipment availability, reduce costs, minimize inventory, and increase labor productivity (Assis 2010).

RCM, in its turn, is a process used to determine what should be done to ensure that any physical item continues to perform the functions required by its users in its present operating context. The efforts needed to study the law of machine life, equipment degeneration curve and anticipating failures through probabilistic calculations. RCM was born with a qualitative approach, which has been modified with the introduction of probabilistic methods to study failures and analysis of costs and risks associated with equipment breakdown and loss of availability (Moubray & Network 1997; Fogliatto & Ribeiro 2009; Selvik & Aven 2011).

If, on one hand, TPM is an extension of the Japanese philosophy on losses elimination, directed to the maintenance area, on the other, RCM uses quantitative methods and analysis to increase the likelihood of a physical component or system operating as it was designed to, according to its life cycle and with minimal maintenance needed(NASA

2000; Mason et al. 2015; Alebrant Mendes & Duarte Ribeiro 2014).

The central objective of this article is to develop a literature review on the two systems of maintenance management, considering the fundamentals, key techniques and the implementation process involved. Another objective is to compare the two systems critically, checking the gaps observed in each of them.

II. INDUSTRIAL MAINTENANCE MANAGEMENT

Maintenance is the combination of all technical and managerial actions during the life cycle of an item, to ensure its full operation in its required function (Fernández & Márquez 2012). The maintenance function should monitor and maintain facilities, equipment and work environments. It should also devise, organize, execute and check the work and ensure the nominal operation of the item during work periods, minimizing time-outs caused by breakdowns or resulting repairs (Verma et al. 2010).

Maintenance management, therefore, is the proper management of failures, availability and performance of the physical assets of an organization, so they may function according to the requirements expected within its life cycle (Cheng et al. 2008; Alebrant Mendes & Duarte Ribeiro 2014).

Maintenance strategies are the different types of tasks including actions, procedures, resources and time. These activities must be conducted in accordance with the established timetable to ensure the maintenance of the target assets (Bakri et al. 2012). Maintenance and planning strategies can be properly updated based on data extracted from feedback of the items performance. The configuration of a supporting system for such strategies depends on many factors, such as the complexity of maintenance tasks, the ability of the employees and plant availability, and is, therefore, a critical problem in maintenance management (Rodrigues & Hatakeyama 2006).

In modern production systems, the product or service and maintenance requirements are the main outputs, i.e., parallel to the production, there is the maintenance process. Maintenance is a system with activities performed in synergy with the production systems. Maintenance activities are so numerous and complex that they require effective management and a well-structured organization (Muchiri et al. 2011; Singh et al. 2013a; McCarthy & Rich 2015).

The maintenance function can be understood as three large dimensions: corrective maintenance, with responsive actions, i.e., acts after the occurrence; preventive maintenance, which is proactive, programming interventions before the occurrence, whether predictive in nature or of a systematic approach or even based on a plan; and finally, reliability dimension, which deals with programming based on the analysis of probabilistic failure and the notion of risk(Xenos 2014).

Corrective maintenance is every intervention conducted in the machinery, equipment and complex systems after the occurrence of damage, so it is a reactive modality. It was the prevailing modality in organizations until the middle of the 20thcentury, mainly because– when observing the maintenance sector alone –, it is the one with the lowest cost, though, from a systemic view of the organization, the cost of production downtime can result in heavy losses for the companies. It is common to confuse corrective maintenance with unplanned maintenance, usually in less developed companies in this sector, for corrective maintenance eventually occurs due to a lack of planning (unforeseen corrective), however, maintenance can be corrective and planned, especially when the preventive maintenance is not more economically advantageous (NASA 2000; Assis 2010; Xenos 2014; Alebrant Mendes & Duarte Ribeiro 2014).

Preventive maintenance starts gaining ground after the second half of the 20th century, when maintenance starts being a strategic function in business. This type of maintenance is planned and follows a scheduled plan of periodic maintenance for all tangible physical assets. It stands out especially with the emergence of the Japanese philosophy of lean production, along with technical and quality management concepts. Preventative maintenance is essentially proactive, with actions taken to prevent failures and, thus, maintain the operation of the equipment. It involves some systematic actions, such as inspections, exchange of parts, and renovations. The main objective of preventive maintenance is to reduce the frequency of occurrence of failures and their severity (Kelly 2006; Alsyouf 2009; Igba et al. 2013; Singh et al. 2015).

Within preventive maintenance emerges predictive maintenance, with a conditional bias made possible by the development of engineering and of the learning machine branch. Predictive maintenance evaluates symptoms of the equipment, allowing the optimization of parts exchange or components of reform, and extending the maintenance interval, since it enables the evaluation and prediction of when the component is close to its useful life limit. It is a proactive and reactive approach, proactive because it comes from a maintenance plan, but reacts from symptoms assessed via prediction by sensory inspection or via prediction by instrumental inspection (Sharma et al. 2006; Aspinwall & Elgharib 2013; Jain et al. 2014).

At the end of the 20th century, with the advancement of aerospace, reliability study becomes indispensable for the management of maintenance. Above all, philosophies based and focused on reliability stand out, directing the focus to the study of law of life in the equipment and the optimization of maintenance, regarding reserve equipment resizing (spare), failure probability, trials and tests via sampling (Fogliatto et al. 2009;Yssaad et al. 2014).

III. TOTAL PRODUCTIVE MAINTENANCE

Nakajima (1988) introduced the concept of TPM in Japan in 1971, as the productive maintenance performed by all employees through activities in small groups to ensure that the equipment is operated at 100% capacity, 100% of the time. TPM is an approach to maintenance that optimizes the effectiveness of the equipment, seeks to correct failures, and promotes autonomous maintenance by the operator during day to day activities, involving the whole workforce (Nakajima 1988; Chand & Shirvani 2000; Aspinwall & Elgharib 2013; Marín-García & Martínez 2013).

TPM is one of the most misunderstood and misapplied concepts in contemporary organizations. It is not just a maintenance program or improvement plan, but a strategic operating philosophy that involves the entire organization (Souza 2004). The main objective of TPM is to restructure the organization as a whole, as improvements that should be incorporated tothe equipment and to people (Tondato 2003).

TPM is initially organized into5 pillars: Autonomous Maintenance; Planned Maintenance; Education and Training; Specific Improvement; and Initial Control. This initial approach was implemented in 1971 in the Niponndenso company, seeking to achieve operational efficiency, which became known as "Production TPM"(Nakajima 1989). In 1989 a theoretical improvement in concepts of the TPM happened and the "Company Wide TPM" arose, bringing a holistic view of an expanded TPM for the entire organization (Chand& Shirvani 2000; Marín-García & Martínez 2013). Other three pillars were incorporated: Quality Maintenance; Hygiene Safety and Environment; and Administrative Areas (Figure 1).

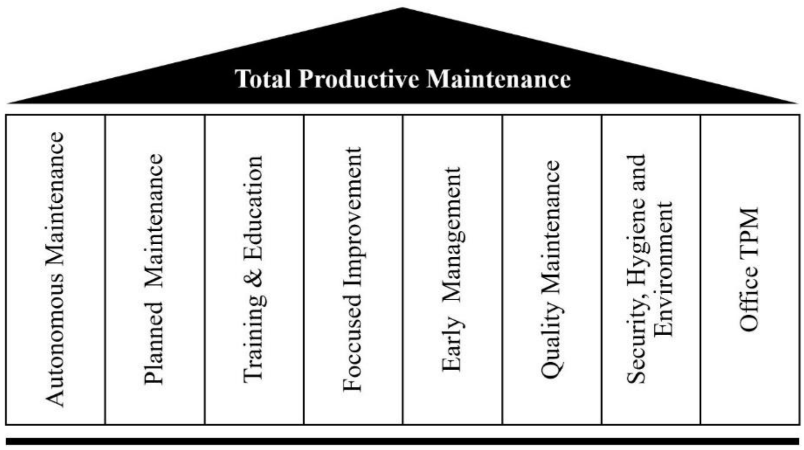

Figure1: The eight pillars of TPM(Ahuja& Khamba, 2008; Singh et al., 2013b)

In terms of organizational culture, the main purpose of autonomous maintenance is that employees are responsible for the machines, looking at them as "daughters" or "owners". This creates a sense of responsibility and appreciation of the work performed by employees (Nakajima 1988).

The Planned Maintenance pillar is essentially one of the most important points of decision-making on the management of maintenance (Nakajima 1989).

In the literature, there is a proposal for a multi-objective programming model for preventive maintenance and replacement supplies schedule in manufacturing systems(Moghaddam 2013). There is a maintenance planning model through mixed-integer linear programming for resource constraints (Manzini et al. 2015). The non-linear programming for manpower allocation optimization for maintenance is used (Ighravwe& Oke 2014). There is the proposal of a full solution algorithm for maximizing the availability of resources, taking into consideration the reliability of physical assets and aircraft maintenance requirements (Gavranis& Kozanidis 2015). And a reliability-based model to resupply parts and maintenance planning based on time (Wang 2012).

The Education and Training pillar is one of the critical factors to a successful TPM program, being the basis for effectiveness in the other pillars, thus achieving the two main goals of TPM, zero failures and zero waste (Seng et al. 2005). The successful implementation is linked to the way people are managed and the culture proposed by TPM is asserted to the employees. This requires a long-term process with training and organizational education (Rodrigues & Hatakeyama 2006). TPM must be understood as a methodology for human initiative at the factory.

The Specific Improvement pillar is the process of restoration and cleaning of physical assets evaluated and monitored for maintenance. Also known as “Kobetzu Kaizen”, the specific improvement is related to the maintenance plan necessary to bring the equipment to the “zero state” through quality tools, with OEE results of the equipment being monitored. The pillar is essential, especially for critical equipment. Used to remove the eight large losses that reduce the overall efficiency of the machine. Generally, it requires financial investments and management efforts directed at the focus equipment to increase its availability and delay the natural degeneration process, i.e., extending its useful life (Nakajima 1989; Xenos 2014).

The initial control pillar not only develops the project focused on the equipment, it also aims to implement a new project that contemplates the integration between man and machine, considering the environmental conditions and the production condition (Assis, 2010; Fogliatto et al., 2009; Xenos 2014).

Beside the 5 first pillars, there are other three pillars, the result of a more recent approach to TPM: Quality Maintenance; Safety, Hygiene and Environment; and TPM Office (administrative areas). The Quality Maintenance pillar (*HinshitsuHozen*) intends to operate in the elimination of losses linked to the equipment’s quality, i.e., in its assertive performance, establishing conditions in the equipment that do not produce failures or defects in the final product. The second pillar is linked to machine safety conditions regarding human manipulation, as well as the emission of pollutants and all those concerns for environmental issues. Finally, in the 21st century, along with the development of the Lean Office, TPM was advanced thinking of the administrative areas, through the adoption of the OEE focused on administrative matters (Ahuja & Khamba 2008; Prakas et al. 2012; Jain et al. 2014).

In the application of TPM policy, a feedback system is implemented, to mediate the evaluation of the system. This tool is called OEE (Overall Equipment Effectiveness). The OEE (Equation 1) is an indicator that evaluates the effectiveness of a certain manufacturing operation on a machine, which aids in the precise search of problematic areas of the processes, providing answers that can be used to implement improvements (Aspinwall & Elgharib 2013).

$$OEE = Availability \times Performance \times Quality \quad \text{Equation (1)}$$

Availability is the productive useful time, compared to the time actually used, discounting the scheduled downtimes and lack of productive demand. The performance is linked to the cadence of the equipment and compares the theoretical cadence, scaled production output, with the actual cadence, the actual output the machine is able to operate. In turn, quality is linked to the production of conforming items, compared to all the produced item (Fernández & Márquez 2012).

The implementation of a TPM system must take into account its fundamental pillars (Nakajima 1988). However, the implementation process is not uniform. Numerous works of various authors present TPM implementation process in the clothing industrial environment. Chart 1 presents a summary of some works focused on TPM implementation.

Chart 1: TPM

TPM, as discussed above, does not have its implementing steps defined, since it is directed according to the application of its pillars. TPM is incorporated into the foundations of lean production and Total Quality, so the consolidation of the implementation will be achieved taking into consideration the implementations introduced (Chart 1) and the implementation methodology of Lean Six Sigma (Tenera & Pinto 2014). It goes through the following steps: (1) Definition, (2) Measurement, (3) Analysis, (4) Improvement and Development, and (5) Control. Thus, research consolidates TPM with the following steps:

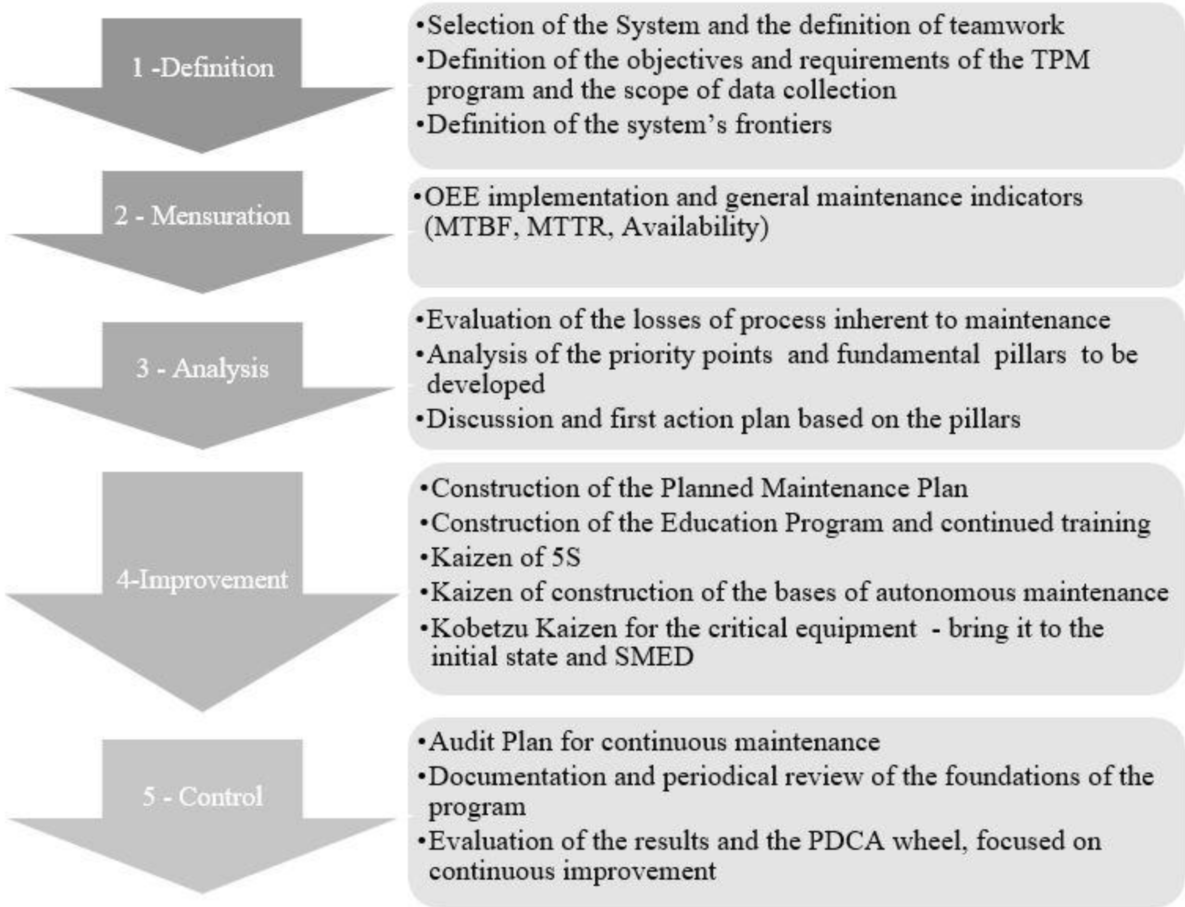

Figure2: Consolidation of TPM implementation

The first stage concerns the definitions inherent to the production process where it will be implemented, the team responsible for the implementation and the definition of the scope of the TPM Program project. In this first stage, we outline the objectives and the metrics selected for evaluating the program results. Key information that should be collected to develop TPM are defined and the implementation strategies of the pillars are established.

The second step is the measurement of key indicators. At this point, key indicators of maintenance performance are implemented, highlighting the OEE – the primary metric used by TPM. As observed inChart 1, some authors propose the measurement of the OEE in the laststeps of TPM deployment, believing that first program bases must be developed, and only then continued control metrics should be explored. However, most authors corroborate the implementation of the indicators in the early stages, as well as the process of implementing the Lean Six Sigma. The idea of implementing in the early stages makes sense, for it generates instant comparison of program effectiveness, faced with the objectives planned and the initial pre-implementation condition.

The third step is the analysis and evaluation of the initial conditions. At this stage, the impacts of production losses are evaluated, through the evaluation and discrimination of the OEE of the equipment and each step of the production process being studied. With this, the priority pillars to be developed in the scope of the TPM program are defined. Guided by the eight fundamental pillars, the first action plan is drawn up to start the TPM implementation process.

The fourth step of improvement is the implementation process of the program itself. Based on the pillars and the implementing process studied, key points were highlighted: the construction of a planned maintenance plan, the education program and ongoing training and numerous Kaizen being performed (5S, autonomous maintenance, SMED, Poka-Yoke, etc.).

The program should start with the two fundamental pillars: the first being the planned maintenance, which outlines the actions of the maintenance function, and the second pillar being that of education and training, which is the heart of the program: participation and creation of an organizational culture that will subsidize implementation of TPM, which is an organic system focused on action and human performance and continuous evolution.

Still in the context of implementation, the Gemba Kaizen are developed and applied. It is known that in any Lean Manufacturing program, the first step of implementation is the construction of a 5S program, which lays the foundation for the following steps. Then, the studied implementations point out to the development of the autonomous maintenance plan, which is closely linked to the education and training program; employees need to be trained and educated in decision-making and to perform simple maintenance operations on the equipment. The following steps are the introduction of the SMED, to reduce setup time and increase the availability of the equipment and of the Poka-Yoke, to increase the compliance of the produced items, thus reducing scrap rates and rework production rates.

Finally, the last step is centered on control. At this stage, indicators and metrics are consolidated and evaluated, as well an internal plan of program audit is developed. It is at this point that one of the most important actions should be established: the process of documentation and registration of the implementation that, alongside the continuous improvement plan, should periodically be reviewed.

IV. MAINTENANCE CENTERED ON RELIABILITY

Since the end of World War II, the United States has dominated two points in the industrial development: (1) technological innovation, which created needs in the consumer market; and (2) production volume, due to the consolidation of the North American industry in world markets. In this sense, since the 1960s, quality management and operational efficiency have gained prominence in the search for industrial systems, either to increase the availability of physical assets or to increase the productivity of production lines and cells (Lazzaroni 2011).

The aerospace industry developed significantly during the Cold War, and even in the 1960s, began studying components to determine the rate of equipment failure in the aircraft industry. We can call it a prelude to the RCM system (Smith & Hawkins 2004).

The RCM maintenance system is defined as a process used to determine what should be done to ensure that any physical item is able to continue performing the functions required by its users in its present operating context (Moubray& Network 1997; Carretero, Pérez, García-Carballeira, et al. 2003; Smith & Hinchcliffe 2003).

Therefore, it is necessary to answer the seven basic questions of an item under review: (1) What are the functions and performance standards of the items in their present operating context? (2) How do they fail to fulfill their functions? (3) What are the causes of each functional failure? (4) What happens when each failure occurs? (5) What are the consequences of each failure? (6) What can be done to predict or prevent each failure? (7) What should be done if there is no appropriate preventive task?(Mendes & Ribeiro 2011; Smith & Mobley 2011).

RCM is known as “reliable from its design”, an approach based and focused on reliability. The program aims to achieve security and reliability inherent to the ability of the equipment at a minimum cost. The fundamental objective of the RCM is to allow the equipment the opportunity to achieve the highest level of reliability consistent with safety, the environment and the operational goals, favoring profit for the organization (Manzini et al. 2015).

This is achieved by addressing the root causes of system failures, reducing them or predicting its failure modes. The main objective of RCM is to establish a systematic process of analysis that would allow maintenance tasks of any physical item to be defined, aiming to ensure reliability and operational safety at the lowest possible cost. In other words, preserve the system functions, identify failure modes, determine the importance of failures and select planned maintenance activities that are more effective and applicable (Smith & Hinchcliffe 2003; Igba et al. 2013).

To establish these objectives, the author proposes the application of seven steps, as illustrated in Figure 2:

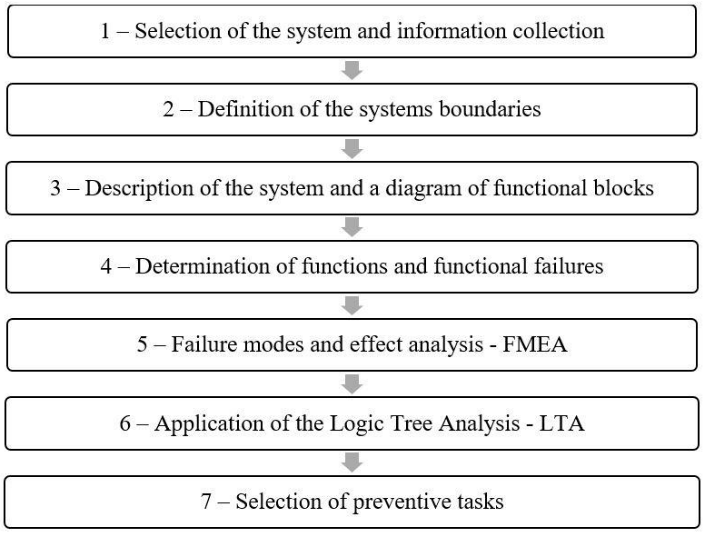

Figure3: Stages of RCM implementation

RCM operates in various dimensions of industrial management, especially regarding cost reduction during the life cycle of the equipment. This system acts directly on the study and evaluation of the modes of equipment failure, of capability, i.e., working regularly with minimal intervention, and in the prediction and study of failures regarding reliability. Maintenance seeks to ensure product quality through efficiency and proper equipment operation. To ensure the desired quality, reliability and maintenance engineering have processes and ways to ensure it, under certain levels of reliability, through the perception of the life cycle stage where each equipment finds itself in (Lazzaroni 2011; Heo et al. 2014).

The basic tools used in the RCM with the context of industrial maintenance are interrelated. We start with the initial analysis of the physical asset lifecycle. The reliability engineering, the human factor, the FMEA application and the related logistical support intend to ensure the desired quality for the asset. Each area in turn has specific techniques and procedures to act in economic and effective maintenance (Alebrant Mendes & Duarte Ribeiro 2014).

The FMEA (*Failure Mode and Effects Analysis*) is a method for analyzing potential reliability problems in the development cycle of the project, making it easier to take measures to overcome these issues, thus revaluing the reliabilities through design (Ebrahimipour et al. 2010). It is a technique that aims to: (I) recognize and evaluate potential failures that may appear in a product or process; (II) identify actions that could eliminate or reduce the chance of occurrence of these failures; and (III) document the study and create a technical reference point of procedures and best practices (Fogliatto et al. 2009). Among the advantages of using FMEA, the aid in identifying the parameters to be controlled to reduce or detect failures stands out, as well as the help in prioritizing the potential failure modes and objective evaluation of alternatives, and the structure of the documentation work to establish a theoretical and technical framework (Arabian-Hoseynabadi et al. 2010).The FMECA is a variation of the original FMEA and takes into consideration the risk analysis through probability and stochastic scenarios (Yssaad et al. 2014). The FMECA is currently called Military Standard MIL-STD-1629A and had its beginnings in the automotive industry, during the 1970s.The FMECA has a critical analysis phase that uses reliability study, leaving the traditional FMEA with a more quantitative approach (Trafialek & Kolanowski 2014; Mkrtchyan et al. 2015).

Therefore, the RCM serves as a guideline to identify maintenance activities with their respective frequencies, supporting the most important elements of the environment under consideration. This system is not a mathematical formula, its success is based on a functional analysis and the evaluation of particular operating scenarios performed by a review team, their efforts allowing the generation of a flexible maintenance management system, adapted to the actual maintenance needs of the organization (Smith et al., 2003).

The implementation of a RCM system provides implementation steps consolidated by philosophy. However, the implementation process is not uniform. Numerous articles by various authors show the RCM implementation process in industrial environments.

Chart 2: RCM implementation

RCM is a system that has a better-defined scope of implementation, despite the variations recorded in Chart 2. The actions were divided into four main steps: (1) Definition; (2) Diagnosis and Analysis; (3) Implementation; and (4) Control and Evaluation.

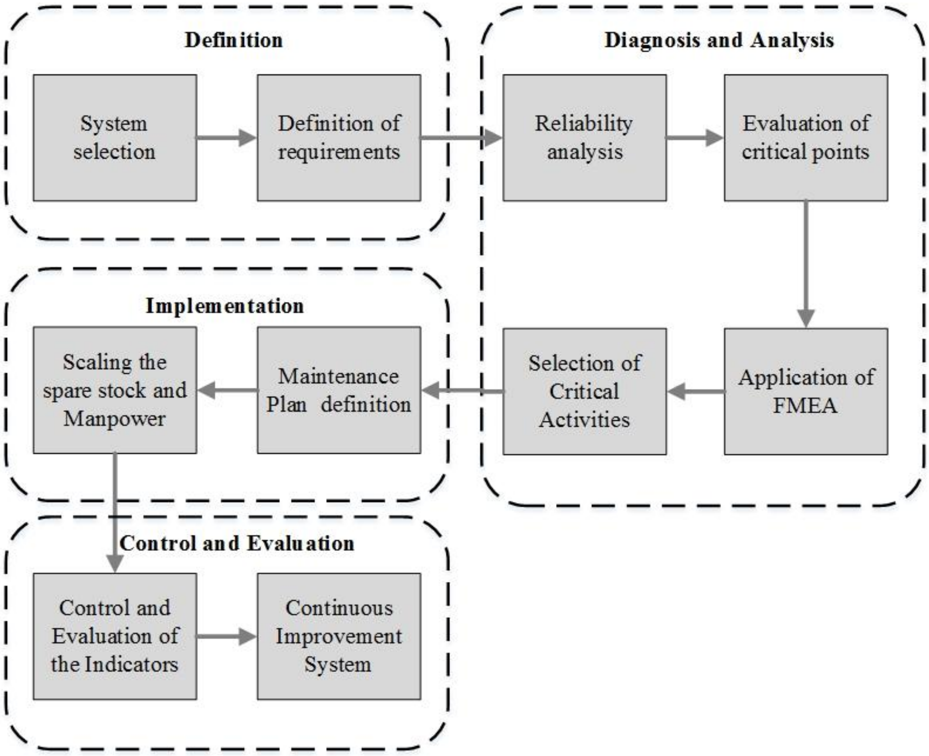

Figure4: Consolidation of the RCM implementation process

The definition step includes system selection and definition of requirements, i.e., we define the project scope, the main guidelines and the definition of the implementation team. The definition of requirements ranges from the allocation of employees to the investment required for the implementation of the RCM.

The second step is inherent to diagnosis and analysis. The RCM allows for a consistent focus directed to this macro step. RCM is designed based on the diagnoses obtained from information and operational data collection. The step includes the assessment of the critical points, the reliability analysis, has terms of key indicators such as MTBF, MTTR, Reliability, Probability of Failure, Risk Function and Availability (A). In it, we apply the FMEA, which will provide the necessary foundation for the selection of critical activities and of priority equipment during its implementation.

In the third step, the maintenance plan is defined and implemented, taking into consideration the items that require preventive, predictive and/or corrective maintenance. Also a part of this is the inventory of spare materials, productive rearrangements for redundancy to improve system reliability and allocation of manpowernecessary for putting into practice the maintenance plan.

Finally, the last step, control and evaluation, we assess the implementation of the system and the indicators chosen. We also have the development of a continuous improvement plan for reassessing the indicators goals.

V. CRITICS TO TPM AND RCM

5.1. Analysis on TPM

The main characteristic of a TPM program is being organic, i.e., based on human iteration and the continued development of the system, through continuous improvement proposed by the lean idea.Rodrigues et al. (2006) have argued that the main reasons for failing to implementa program of this nature are directly linked to the performance and commitment of those involved in the implementation and maintenance of the TPM program. Nakajima (1988), the father of TPM, continuously emphasizes the need for the commitment of all the company's employees to the success of the program. Thus, the Education & Training pillar transposes the importance of others, gaining a structural and decisive connotation

In this sense, the TPM is people-oriented, and not focused on processes, it is a system that incorporates the fundamental principles of the lean production: involvement of people and focus on eliminating waste. For this reason, it may oftentimes neglect the processes, the need for technique and observation of how to put into practice what each pillar proposes.

Concerning the planned maintenance pillar, TPM stresses the importance of planning, but does not delve further into fundamental questions:

1. Which equipment should undergo preventive maintenance?
2. How often should planned interventions occur?
3. What are the goals of the Planned Maintenance pillar?
4. What are the gains when there is no planning?

The answer to these questions goes beyond the borders of TPM itself, and its decision and determination is often in the hands of program managers, based on their history and knowledge of the process itself. The lack of a more robust quantitative framework, in the scope of the program itself, can lead to decisions that are based on empiricism, rather than the methods, more robust models and techniques for the ascertainment.

Another point observed is linked to the specialized continuous improvement pillar (KobetzuKaizen), which, in the context of the lean production, means that the equipment can be cyclically renewed, without the continued need for replacement. This approach is very coherent, because it focuses on the actual need for the acquisition of assets, “do I really need this new equipment”, “recovering what I already have is not more advantageous than purchasing a new one?”. Oftentimes, the more consistent decisions are geared to the recovery and improvement of an asset, which underlies this pillar. However, as shown in Chapter 2, all equipment hasanusefullife that often follows the model of the Bathtub Curve.

These principles should take into account that all equipment has anuseful life, as well as a phase of natural degeneration. The specific improvement pillar is fundamental for monitoring, and also expanding this usefullife. Degeneration, though, is inevitable, and only with the use of quantitative methods inherent to the failure rate, it is possible to measure and evaluate the possibility of exchange, whereas, obviously, economic aspects and the probability of failure of these assets are taken into consideration.

Regarding performance indicators, the TPM focuses its assessment on the OEE asa fundamental metric. It is a complete and relevant indicator, but it does not take into account issues related to financial aspects, failure rate, probability of failure and maintainability.

5.2. RCM analysis

RCM is a program that initially, even though it proposes a look into reliability, only touches the techniques and quantitative methods inherent to reliability engineering. From the mid-1990s,it started gaining a more quantitative connotation in terms of analysis and definition of requirements. It is a program targeted and focused in the process and behavior of equipment during its law of life.

RCM is much more a management system than an operational one, for it focuses on the process, is less directed people than the TPM. It has a clear strategy of top-down, in which management defines the requirements and procedures to guide and implement the operation. It requires specialized and skilled labor regarding reliability engineering, statistical process control and operations management. The accuracy, rigor within the limits of control, programming, and continued monitoring come from the industry in whichthe system was born:the aerospace industry.

Since it targets process, employee appreciation, mainly the operational ones, may be left on a secondary level of importance, which may negatively affect the successful implementation of RCM. An opportunity of inclusion may occur in the implementation of the FMEA, one of the fundamental steps of RCM, but the scores and evaluations are usually performed by the managers responsible for the area.

One of the main criticisms of RCM is, thus, that it is an excellent system to control the maintenance function, but has gaps in the process of improvements geared to the production process.

VI. Comparative Analysis between TPM and RCM

With the critical analysis, it becomes clear that the focus and the center of the two systems studied are distinct.Figure 3 summarizes the key differences between the two classical approaches to industrial maintenance management.

For comparison,we defined some aspects to be analyzed about the TPM and the RCM: school, origin, fundamental focus, implementation strategy, team building process, central method of application, work approach, system organization, fundamental objective and primary metric.

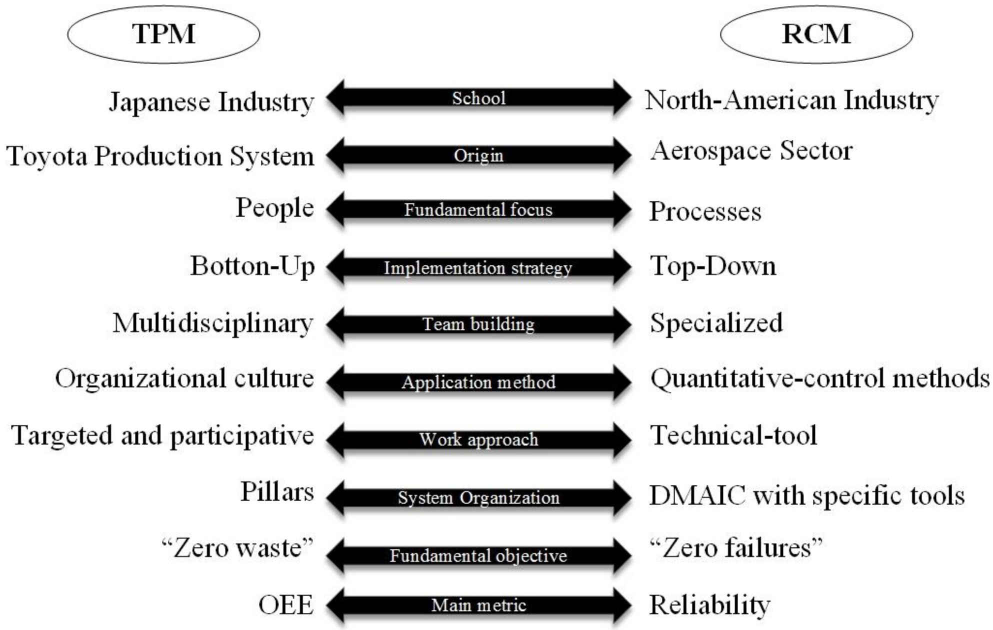

Figure5: Comparison between TPM and RCM

6.1. School and Origin

Regarding school, it is the industry in which the maintenance management systems were born. It is important to contextualize the school to understand the foundations, objectives and intrinsic characteristics. The RCM comes from the North-American industry while TPM has its origin in the Japanese industry.

The North-American industry initially developed along the industrial revolution, based in Fordism, Taylorism and the portfolio changed brought by General Motors. This is a school that values specialization of activities and optimization of the production system,using new technologies. These characteristics are present in the development of RCM.

More specifically, RCM has its origin in the aerospace industry, which has as one of its main characteristics the use of cutting-edge technology and intolerance of failure. From the 1950s and 1960s, this industry, in the context of the aerospace race during the Cold War, begins to develop techniques and procedures aimed to mitigate failures and raise the levels of reliability of processes and equipment on never before achieved levels. The reliability engineering is developed with techniques and mathematical models, leaving the context of the war and entering the industry.

On the other hand, the Japanese industry, with further development in the Post-World War II, has other peculiarities brought on by the Toyotist model, such as the elimination of waste and development of human resource. In this theoretical framework, we have the birth of the TPM.

The Toyota Production System acts on waste elimination and, in its context, the Total Quality and TPM also addresses this elimination. The TPM, sectioned into pillars, seeks failures, its causes and continued improvement.

6.2. Fundamental focus

The Total Productive Maintenance, coming from the concepts and fundamentals of the Toyota Production System, has a broad appreciation of the human role in manufacturing processes. It understands that a factory is a living organism, and that the performance of its employees is the key to it being successful or not in achieving its objectives. The Fundamental Focus is on people, since waste is basically caused by human decisions and the perpetuation of good practice only occurs with a change in the organizational culture.

Understanding where RCM comes from and its commitment to the development of techniques and the adoption of technologies, it is consistent that its targets is more focused on processes. The technique is more important than the implementing agent. Human action is part of a puzzle, where the actions are well defined by the specialization of labor and the determination of what is standard work. The system understands that actions must be rational and, therefore, performed as specified, without deviations. Since man is susceptible to error, by their innate condition, there is a tendency of constant industrial automation in environments guided by RCM, a system intolerant to deviations.

6.3. Implementation Strategy and team building

The TPM implementation strategy is the bottom-up type, building a multidisciplinary team. In this strategy, we comprehend that the floor-to-factory operators, for experiencingit in their daily lives, are better equipped to understand the main demands and improvements for the sector. It is a participatory strategy and takes into consideration the experience of the multidisciplinary team for making decisionsregarding objectives, activities and goals to be drawn.

RCM, however, by focusing on the process, has its process of building specialized teams. The most relevant for the project are those who best understand the process. Thus, this team makes decisions that all on lower levels should act on, so this is, therefore, a top-down strategy.

6.4. Application method, work approach and system organization

RCM values the use of quantitative methods and control measures in the decision-making process. These tend to be Cartesian, through the solutions identified by the methods. The approach to work is so technical and tool oriented, with the adoption of tools and techniques in the improvement tasks of maintenance management.

TPM, on the other hand, by emphasizing the human factor of work, believes that there should be a change in the organizational culture to achieve its goals, with a working approach based on its fundamental pillars. The education and training pillar is also cross-cut to all others. Education is directly linked to culture, which should be directed to its fundamental principles and dogmas.

TPM is people-oriented, while RCM focuses on the process. While TPM plays more on the philosophical field, regarding the generation of an organizational culture, RCM sets its focus on technique and support for decision-making tools.

We note that RCM and TPM implementation process follows the same logic and organized perspective, with the following macro steps: (1) definition of the system, the team and the project scope; (2) information collection and analysis; (3) implementation; (4) monitoring and control focused on data review and continuous improvement. This organization is also compliant with the classical PDCA Cycle and the DMAIC Cycle models.

The need to plan is treated as a critical point in RCM and TPM implementation. While RCM translates this as a preventive maintenance plan supported by the FMEA developed, TPM uses the planned maintenance pillaras an attack point for lack of planning. TPM is, thus, widely criticized for making the equipment to have preventive maintenance, while RCM takes into account the risk and costs associated to decide the most consistent model is preventive or corrective maintenance; both are consideredplanned maintenance, even though they are both corrective.

6.5. Fundamental objective and metric

We would like to emphasize that the basic objectives, although targeting different points, converge. While the TPM focuses on eliminating waste, especially those that impact on the OEE. RCM focuses on the elimination of failure, by reducing the probability of asset failure, which reduces thus the associated risk.

OEE is the main indicator used in TPM, it isa global mode that assesses the impact of the waste generated by the maintenance activities. In RCM, reliability engineering and its indicators are the main guide for the effectiveness of work in the maintenance function.

VII. CONCLUSION

This article depicts two maintenance management systems established by the industry and the literature, TPM and RCM. They come from different and competing schools. While TPM comes from Total Quality and the Japanese lean production, RCM comes from the USaerospace industry. Both have been consolidated in literature over the past three decades. However, an analysis concerning the implementation process of each and the implementation between them is the contribution of this research.

We defined matching points between TPM and RCM, surrounding the core objectives and the search for optimizing the maintenance function. We found that the implementation structure in both cases was guided directly or indirectly by the PDCA cycle and the planning phase has a key role in a successful implementation.

We also studied the shortcomings of the two maintenance management models. Since they have different guidelines – TPM focuses on employees and RCM on process – the gaps appeared naturally. There are many different aspects of the models, but some observed are conflicting: the divergence in strategy and team building. Having a top-downimplementation strategy, focused on expertise and leadership skills of those chosen to manage the project, which is the case of RCM. On the other hand, TPM leans on a qualified and multidisciplinary team, with members of different hierarchical levels. It uses a bottom-up strategy, as part of one of the maxims of the lean production, which states that “no one knows the process and needs better than the operator himself” .By focusing the maintenance program on the process, RCM may neglect the continued participation of those involved, which may jeopardize the health of the program, long-term.

A contribution that touches the main objective was the creation of the implementation framework of TPM and RCM. This occurs because the systems are not implemented in a linear and uniform fashion, so within academic research, it is an important contribution to gather and analyze the literature for the implementation process of TPM and RCM.

One of the main difficulties since these are competing models of maintenance management, was the comparative analysis between the two. We cannot claim that one is better than the other. We can, however, list possibilities for hybrid implementations that address both systems. The first salient point to achieve a consistent comparison is placing the two systems in equal foot during the analysis. Next, we dive deeper into the theoretical characteristics that support TPM and RCM. Lastly, we are able to perform a holistic comparison of the systems.

For new studies, we suggest going deeper into the relationship between TPM and RCM to seek an integration of the two systems. We understand that the challenge of continuous improvement of the production systems seeking to provide increased competitiveness is a growing reality. The use of RCM and TPM policies must be increasingly integrated in order to use what each has the best to offer (best practices, procedures and techniques), without prejudice or conflict of approaches.

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