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Asset management system (ISO 55001) and Total Productive Maintenance (TPM): a discussion of interfaces for maintenance management

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ABSTRACT

In the current globalized scenario, high productivity is a competitive factor for the survival and success of organizations. Ensuring the physical assets of the company is performing its functions while minimizing the occurrences of quality defects and breakdowns is a challenge in the maintenance management. Among the diffused approaches is Total Productive Maintenance (TPM) and, more recently, the asset management system (AMS) of the international standard series ISO 55000. The objective of this work, therefore, is to discuss the interfaces between the approaches in order to clarify the correlations and sufficiency of the TPM for an AMS. For this, a three-part methodology was structured: content review, correlation of the themes and discussion of interfaces. It was observed that TPM is a model for maintenance management and widely used in the manufacturing industries, while the AMS is a broader approach. Therefore, it was evidenced TPM can be an applicable management model to handle the maintenance requirements of ISO 55001, although it is not sufficient by itself. Thus, it is expected that this work will clarify the organizations on the non-exclusive nature of two themes.

Keywords: Asset Management. ISO 55001. Total Productive Maintenance. TPM.

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1. INTRODUCTION

Exposure to the global competitive landscape makes companies face the challenge of increasing the added value of their products and services. For Xenos (2014), high productivity ensures competitiveness. According to the author, a competitive organization "is the one that has the highest productivity among all its competitors and this is the best guarantee of survival."

Although industry has promoted the need to have, simultaneously with technological development, an organizational system, it was not until the twentieth century that the most significant ideas for work organization and business management emerged (KARDEC *et al.*, 2014).

Total Quality Management (TQM) is an approach to achieving long-term business success through customer satisfaction in which all members of the organization participate in improvements in process, in product, in service and in the culture in which they work (AMERICAN SOCIETY FOR QUALITY, 2013). For Lobo (2014), it is a widespread strategic approach that “aims to associate quality with all stages and processes of a company”.

A maintenance management system integrates as part of TQM acting directly on the company's means of production, the equipment. However, maintenance activities have traditionally been regarded as a necessary evil and, only recently, have been recognizing maintenance as a strategic function (XENOS, 2014). For Resende and Dias (2014), over the years, companies have seen maintenance as an opportunity to keep production processes at high levels, whose investments are responsible for preventing production and equipment losses.

Total Productive Maintenance (TPM) is a management model that seeks to improve systems through the elimination of losses, reduction of production failures and downtime and the development of team and equipment (RESENDE; DIAS, 2014). For Netto (2008), it is a management system for the administration of maintenance operations, in which there is a close relationship between people and equipment. Thus, the reduction of costs by reducing of operational failures and defects through TPM is an approach to maintain the company's competitive advantage (GIRÃO; AMORIM; MASIH, 2016).

In 2014, however, a new international standard came into force applicable to maintenance: the ISO 55000 series for asset management. Even though the requirements of ISO 55001 apply to other asset types, the standard is designed to be used for physical asset management (ISO, 2014). Thus, the publication of an international standard leads companies to rethink the maintenance management structure aiming at competitiveness and excellence.

1.1 Problem

Although implementing the standard drives proactive asset maintenance leading to fewer failures, less waste and improved services (IHEMEGBULEM; BAGLEE, 2016), the issue is very recent. For Bo (2015), asset management is still underexplored in manufacturing industries and, for organizations without the immediate demand for alignment of requirements, the likelihood of allocating time and resources to the subject remains very low.

It is also observed that the subject is little explored by the academy according to bibliometric study in the SCOPUS base evidenced by the authors Halasz and Ferraz (2016). In Brazil, the scientific production on the subject is even scarcer. The national articles found aim to review the literature and history without any association with traditional maintenance management models or integrated management with other management systems, such as Tavares and Gomes (2015).

In addition, the international standard ISO 55001, which dictates the necessary requirements for implementation and certification of an asset management system (AMS), is not specific in setting out its statements. In the words of Ihemegbulem and Baglee (2016), "the document can be seen as limited in that it says what needs to be done, but not how to do it." Therefore, questions may be raised by companies that already have organizational models in place for maintenance management, for example, TPM.

In this context, this paper aims to answer the following questions about the interface between asset management system (AMS) and Total Productive Maintenance (TPM):

a) How does the ISO 55001-based AMS relate to TPM?

b) What are the interfaces between the standard structure and the TPM pillars?

c) How does the scope of the TPM relate to meeting the requirements of the standard?

Through these questions, the objectives of the research were elaborated.

1.2 Objectives

The general objective of this work is to discuss the interfaces between the maintenance management based on the asset management system (AMS) according to the framework of ISO 55001 and Total Productive Maintenance (TPM).

To achieve this objective, the following specific objectives are defined:

a) Discuss the principles and pillars of TPM;

b) Review the requirements of ISO 55001 for an AMS;

c) Relate the structure of the ISO 55001 standard with the TPM;

d) Represent the AMS interfaces with the TPM.

1.3 Justification

Among the challenges of organizations is the need to sustain and often improve operational efficiency and customer satisfaction while reducing investment and operating costs (MITCHELL, 2002). For this, there is not a success rule valid for all organizations. However, for companies seeking international performance standards within competitive markets, asset management brings, from the context of the organization, a new proposal to achieve strategic objectives (INTERNATIONAL COPPER ASSOCIATION, 2015).

Although the publication of the ISO 55000 series of asset management systems is an international milestone for the evolution of maintenance management, research on this subject is scarce. On the Science Direct platform, 59 published documents were identified with the search term “ISO 55000” until August 2019, however only 7 of these were actually related to asset management within the scope of the physical assets and scope of the standard.

In Brazil, in a literature review in the annals of the National Meeting of Production Engineering (*Encontro Nacional de Engenharia de Produção*, ENEGEP) and the Symposium of Production Engineering (*Simpósio de Engenharia de Produção*, SIMPEP) in the last 5 years, since the publication of the standard, only 3 papers were identified with the terms “ISO 55000” or “ISO 55001” in their titles and summaries. With the term “Assets”, 105 jobs were identified, however, only 6 other jobs used the term in the context of maintenance and asset management.

On the other hand, the theme of Total Productive Maintenance was present in the national publications of the same events in the last 10 years (2009-2018). During this period, 34 and 37 papers published in ENEGEP and SIMPEP respectively were identified. Most of

them approach the theme through case studies and evaluation of the results, showing an approximation with the industry.

Thus, the development of this work is expected to contribute to asset management research in the context of industrial maintenance. The discussion of the requirements for the asset management system (AMS) as per the international standard series ISO 55000 and the Total Productive Maintenance (TPM) program can give a better understanding of how the approaches relate, guiding organizations and providing opportunities for future research and applications.

To explore the topic more effectively, the work is structured in five chapters. In this first, the introduction punctuated the scenario and justification for the research, as well as presented the general and specific objectives. The remaining chapters are intended for bibliographic reviews, presentation of methods, discussion of results and considerations, followed by references.

2. THEORETICAL REFERENTIAL

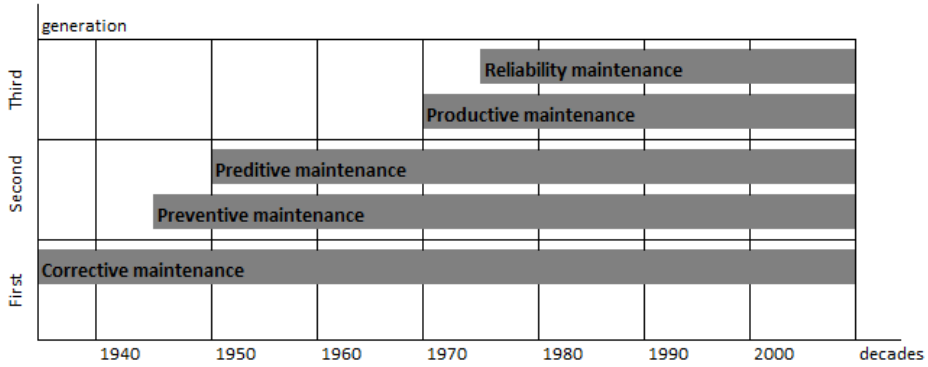
This chapter is divided into 3 sections to present the main research themes. Section 2.1 presents a history of maintenance management evolution. Following, the concepts of Total Productive Maintenance (TPM) and asset management system (AMS) in accordance with the requirements of ISO 55001 are deepened in, respectively, in sections 2.2 to 2.3 for the development of the work.

2.1 Maintenance management

The scenario and discussions established for the maintenance management universe are quite different from a few years ago. According to Bo (2015), maintenance for a long time was seen only as a cost and therefore should be minimized. This context favored short-term decision-making rather than more detailed planning for the future.

In its history, maintenance can be divided into three generations as shown in Figure 1. The first generation represented the era of mechanization, followed by industrialization and automation in the second and third generations. For Siqueira (2014), “each stage is characterized by a different stage of technological evolution of the means of production and the introduction of new concepts and paradigms in maintenance activities”.

Figure 1 – Maintenance evolution



Source: Adapted and translated from Siqueira (2014).

The shift from repair task force maintenance to a structure influenced by project management theories began in the 1970s (BO, 2015). Period in which there was the strengthening of maintenance planning and control given to the most accessible computers and the emergence of the first computerized systems for maintenance management (TAVARES; GOMES, 2015). It was also during this period that the introduction of Total Productive Maintenance (TPM) was introduced, as a reflection of Total Quality techniques (SIQUEIRA, 2014).

In the 1980s, quality control and continuous improvement were introduced. In the 1990s, with system integrations and the introduction of the Balanced Scorecard, new ideas for industrial maintenance emerged (BO, 2015). It was during this period that the concepts of planned maintenance optimization, best production practices, performance indicators and quality standards influenced maintenance (TAVARES; GOMES, 2015; BO, 2015).

Only in the 2000s when asset management was properly developed as a response to the demand for standardization of physical asset management. According to Kardec *et al.* (2014), originally focused on the financial aspect, "came to be considered an activity that, applied to the various areas of the company, promoted an appropriate format for the management of physical assets, providing a greater return for shareholders".

For Tavares and Gomes (2015), maintenance is no longer a mere repair function, but one of the most important functional areas of the company. Therefore, maximizing returns on investments in physical assets, while ensuring safety and environmental preservation, is more critical than ever (STANFORD, 2015).

2.2 Total Productive Maintenance (TPM)

With the end of World War II, the second generation of maintenance history begins, around 1950. According to Siqueira (2014), this period lasted until the mid-1970s and was marked by the effort of postwar industrialization, with dissemination of production lines and industrial processes. Due to the scarcity of skilled labor, costs were rising with failures due to automation processes. It was during this period that the availability and useful life at low costs gained focus on equipment in industrial environments (SIQUEIRA, 2014).

This context motivated the development of preventive and predictive maintenance techniques, oriented to minimize the impacts of failures on processes and means of production. In the mid-1970s, these techniques were organized and integrated by Total Productive Maintenance (TPM) as a result of postwar Japanese restructuring (SIQUEIRA, 2014) by Seiichi Nakajima.

Nakajima was responsible for studying American preventive maintenance from the 1950s and later making visits to manufacturing companies in the United States and Europe during the 1960s. Based on his observations and combining these ideas with Total Quality Control (TQC) and full worker involvement, developed TPM and introduced it to Japan in 1971. In 1987, Nakajima led a mission to the United States to promote TPM at the Fourth International Maintenance Conference, where it aroused great interest in TPM implementation in the USA (NAKAJIMA, 1988).

Since then TPM has undergone improvements over the last decades. According to Palmeira and Tenório (2002, apud Marocco (2013)), the program had 4 generations, as shown in Table 1.

Table 1 – Four generations of TPM

	1st generation	2nd generation	3rd generation	4th generation
	1970	1980	1990	2000
Estrategy	maximum equipment efficiency		Production and TPM	Management and TPM
Approach	Equipment		Production system	Overall company system
Losses	Failures	6 main losses of equipment	16 losses (equipment, human factors and production resources)	20 losses (process, inventory, distribution and procurement)

Source: Translated of Palmeira e Tenório (2002) apud Marocco (2013).

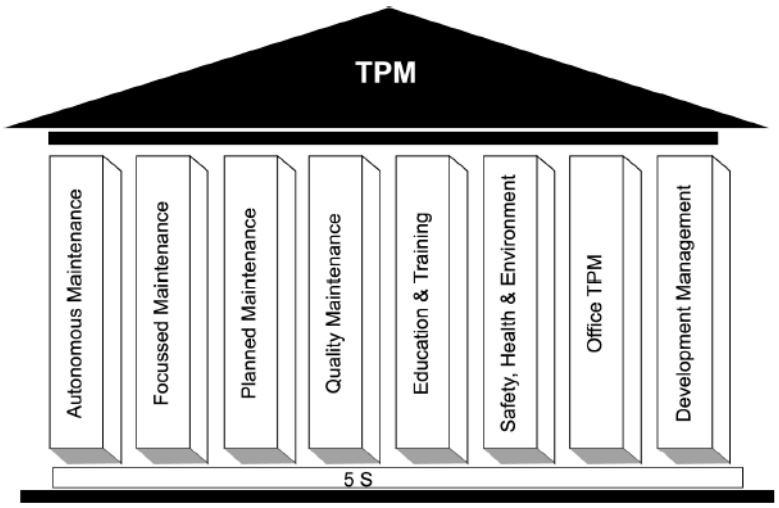
According to Nakajima (1988), the goals of TPM are two: zero breakdowns and zero defects. In the author's words, "TPM is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes operator self-maintenance through routine workforce activities." Thus, we highlight the three most important characteristics of TPM: activities to maximize equipment effectiveness, autonomous maintenance by operators, and small group activities led by the company (NAKAJIMA, 1988).

For Netto (2008), the central idea of TPM is to arouse in the operator the care relationship that he must have with his work equipment. Denis (2008) adds that the program is a profound change in the mindset of the operator. According to the author, the program alters the old paradigm that operators work on machine operation and maintenance personnel, when in trouble, repair. However, according to TPM principles, everyone is responsible for the equipment.

Ahuja and Kahmba (2008) carried out an in-depth literature review on TPM and represented the program in eight pillars, aligned with what the Japan Institute of Plant Maintenance (JIPM) suggests and promotes, and depicted in Figure 2:

1. Autonomous maintenance (AM)
2. Focused maintenance
3. Planned maintenance
4. Quality maintenance
5. Education & Training
6. Safety, Health & Environmental
7. Office TPM
8. Development management

Figure 2 – Eight pillars approach to TPM implementation



Source: Ahuja e Khamba (2008).

As noted in Figure 2, the foundation of the TPM structure is the 5S. According to Singh et al. (2012), problems cannot be recognized if workplaces are disorganized. In this way, cleaning and organizing help identify problems and, once they are visible, provide the opportunity for improvement.

The goal of any TPM program is therefore to improve productivity and quality along with an increase in employee morale and job satisfaction (Singh et al., 2012). Everyone in the company, at any level, should be involved in the culture and activities for TPM's success (MAROCCO, 2013).

2.3 Asset Management System (AMS)

Asset management had its first discussions in the early 2000s. However, it was not until 2014 that the series of international ISO 55000 standards for asset management was published, formalizing a new stage for maintenance management. The evolution until the publication of the standard was structured by Kardec et al. (2014), highlighting the main facts and entities involved, as shown in Table 2.

Table 2 – Asset management evolution

Year	Entity	Fact
2000	National Property Management Association (NPMA) and American Society for Testing and Materials (ASTM)	"E53 Asset/Property Management Standards Committee" for the development, maintenance and dissemination of practices, standards and performance standards for asset management systems and personal property asset lifecycle management.
2004	Institute of Asset Management (IAM)	Development of Publicly Available Specification 55 (PAS 55), published by BSI
2008	British Standards Institution (BSI)	PAS 55 Publication, Version 2
2009	BSI and International Organization for Standardization (ISO)	Defines PAS 55 as the basis for the international asset management standard.
	ASTM	ASTM E53 decides to join development of international asset management standard
2010 to 2013	ISO	Development of International Asset Management Standard (ISO 55000)
2014	ISO and Associação Brasileira de Normas Técnicas (ABNT)	Launch of the ISO 55000 and ABNT NBR ISO 55000 Standards series (Portuguese version)

Source: Adapted and translated from Kardec *et al.* (2014).

In 2004, the British Standardization Institution (BSI) pioneered the publication of Publicly Available Specification 55 (PAS 55) which was reviewed and revealed a strong need

for good asset management practices. Shortly thereafter, in 2008, it underwent a review. Already in 2009, BSI, supported by the Asset Management Institute (IAM), formed a commission to develop an international standard based on PAS 55 references and other industry learning from around the world (STANFORD, 2015).

Brazil, represented by the Brazilian Maintenance Association (*Associação Brasileira de Manutenção e Gestão de Ativos*, ABRAMAN), participant of the Global Forum on Maintenance and Asset Management (GFMAN), together with the Brazilian Association of Technical Standards (*Associação Brasileira de Normas Técnicas*, ABNT), participated in the creation of the standard (TAVARES; GOMES, 2015). In January 2014, all global effort and engagement resulted in the publication of the ISO 55000 series of standards by the International Organization for Standardization (ISO). It was then translated into Portuguese and valid from March of the same year with the ABNT ISO 55000, ABNT NBR ISO 55001 and ABNT NBR ISO 55002 asset management standards.

It is in ISO 55001, Asset Management - Management Systems - Requirements, where the requirements for establishing, implementing, maintaining and improving a management system for asset management are specified. ISO 55000 and ISO 55002 specify overview, principles and terminologies and guidelines for the application of ISO 55001, respectively. Therefore, it is ISO 55001 that organizations must meet in order to implement and certify a standardized asset management system.

Asset management represents "a cultural change in the strategic planning of companies that add to the traditional view on products and customers to the view of assets and the value they are capable of generating for the business" (INTERNATIONAL COPPER ASSOCIATION, 2015). In this context, the paradigm shift represents a trend towards long-term planning and reinforces the role of maintenance in business sustainability through asset management.

For Stanford (2015), ISO 55001 does not reveal what to do to manage physical assets. The standard, like most other international management standards, provides flexibility in how to meet requirements. Thus, the ISO 55000 series of standards is a detailed and comprehensive standardization that helps the implementation of a physical asset management system in the organization (IHEMEGBULEM; BAGLEE, 2016). However, the standard allows different companies to employ various strategies to meet deployment requirements.

3. METHODOLOGICAL PROCEDURES

3.1 Study object

In engineering research, no method should be privileged over another (BORREGO; DOUGLAS; AMELINK, 2009). For the authors, the choice of the methodology should be guided by the research questions. Therefore, in this work, the use a qualitative approach of exploratory objectives, bibliographic procedure and comparative investigation technique was chosen, according to the research classifications of Gil (2002).

Total Productive Maintenance (TPM) methodology and the asset management system based on ISO 55001 are the main objects of work studies. Understanding both approaches is fundamental to answer the research questions.

3.2 Data collection and analysis procedures

To achieve the proposed objectives, the methodology was structured in three stages:

I. Content review: the literature review identifies the pillars of the Total Productive Maintenance program for maintenance management and the structure and requirements of the asset management system in accordance with ISO 55001;

II. Correlation of the themes: by means of a comparative analysis, the two approaches in maintenance management are correlated;

III. Interface discussion: through a graphical representation, the interactions between the two approaches to maintenance management are discussed.

4. RESULTS AND DISCUSSION

In this chapter, we present and discuss the results obtained according to the work methodology. To this end, the first section is intended for the presentation of the in-depth content review, followed by the correlation of the themes in the next section and, in the third section, the discussion of the interfaces between the two approaches.

4.1. Content review

It is essential for the correlation of the two themes that the contents be reviewed in sufficient detail for a comparative analysis between the key points that underpin each approach. Therefore, this section presents the results of the content reviews of the eight pillars

that underlie the TPM and the structure and requirements of the AMS in accordance with ISO 55001. For better understanding, TPM pillars are sequentially organized and presented in eight individual subsections:

4.2. Autonomous Maintenance

For Singh et al. (2012), Autonomous Maintenance (AM) is based on the concept that operators take care of small maintenance tasks, concentrating technical maintenance staff for higher value activities and technical repairs. In other words, "it is the maintenance of the equipment made by the operators to guarantee a high level of productivity" (NETTO, 2008). Therefore, operators are responsible for monitoring their equipment during daily activities to prevent them from deteriorating (SINGH *et al*., 2012).

Netto (2008) highlights as objective of this pillar the operator's awareness of his responsibility with his work equipment through autonomous maintenance activities. Among the activities involved are simple tasks such as cleaning, lubrication, visual inspection, retightening among others (SINGH *et al*., 2012). Therefore, AM aims to motivate "the operation and maintenance teams, in a shared way, to reach the common goal of restoring and maintaining the basic condition of the equipment" by stopping its deterioration (PALMEIRA, 2001).

For Palmeira (2001), AM has two other objectives within the TPM. To the extent that it proposes operator performance in equipment, AM aims to spread practical knowledge about equipment functions, common problems and solutions. Still, it aims to awaken an active posture of operators with engineering and maintenance in search of improvements.

The issues addressed by the Autonomous Maintenance pillar, therefore, can be summarized as: promotion of equipment ownership and performance of basic maintenance tasks by operators (AHUJA; KHAMBA, 2008). Thus, the operation of the equipment is sought without breaking and eliminating defects through the active participation of operators (SINGH *et al*., 2012).

4.2.1 Focused Maintenance

The Focused Maintenance pillar aims, through the management of equipment operating information, to propose optimizations through improvement groups to eliminate losses (NETTO, 2008). For Ahuja and Khamba (2008), it addresses the identification and

systematic elimination of losses. Therefore, it is under this support that the organization elaborates the loss mitigation framework by specific tools (e.g., FMEA, why-why).

Specific improvements, as also referenced, maximize overall efficiency of equipment and processes by eliminating waste. For Palmeira (2001), losses are identified, measured and evaluated in order to set reduction targets. By identifying and blocking root causes, teams eliminate losses to equipment efficiency.

This continuous improvement cycle aligns with two other points supported by the Focused Maintenance pillar: achieving system efficiency improvement and overall equipment efficiency (OEE) of production systems (AHUJA; KHAMBA, 2008).

4.2.2 Planned Maintenance

Since Autonomous Maintenance encompasses the simplest maintenance tasks by operators, the most complex and technical tasks fall under the responsibility of maintenance through Planned Maintenance (PALMEIRA, 2001). For Singh et al. (2012), this pillar aims to achieve "machines and equipment free from any breakdown and producing at the quality level necessary for customer satisfaction".

For Netto (2008), Planned Maintenance is responsible for all maintenance planning at its macro level. Maintenance can be performed as preventive maintenance, fault maintenance, corrective maintenance, predictive maintenance and maintenance prevention (SINGH et al., 2012). Because the pillar aims to achieve zero failure, a Planned Maintenance program should combine, at the lowest cost, time-based tasks (preventive maintenance), condition-based tasks (predictive maintenance), and correction tasks (corrective maintenance) (PALMEIRA, 2001).

The issues addressed by the Planned Maintenance pillar, therefore, can be summarized into: efficient and effective maintenance planning throughout the equipment life cycle, preparation of preventive maintenance checklists, and improvement in equipment and maintenance performance indicators (AHUJA; KHAMBA, 2008). Thus, Planned Maintenance is a proactive approach in which it utilizes trained and technical staff to help operators better maintain their equipment (SINGH *et al*., 2012).

For Palmeira (2001), as the implementation of planned maintenance evolves, there is a change in the pattern of predominant tasks by the maintenance team, migrating from predominance of break correction to conditions-based tasks. This pillar, therefore, contributes

to the reach and sustainability of machine availability, optimal maintenance costs and zero failure, among others (SINGH *et al*., 2012).

4.2.3 Quality Maintenance

Through the efficiency of Planned Maintenance and Autonomous Maintenance in production systems, the organization contributes to achieving zero equipment failure. However, TPM also prioritizes zero product defects. Thus, those responsible for the Quality Management System (QMS) must act in conjunction with maintenance management in order to achieve this common goal (NETTO, 2008).

For Ahuja and Khamba (2008), in addition to achieving zero defects, the Quality Maintenance pillar encompasses two other points: tracking and addressing equipment problems and root causes and surveying conditions (machine, labor and material) that impact product quality. In other words, the pillar is focused on customer satisfaction by delivering the highest quality products (SINGH *et a*l., 2012).

It is through Quality Maintenance that the necessary activities are carried out to ensure the manufacture of defect-free products (PALMEIRA, 2001). Once parameters that affect product quality are monitored and identified, specific improvements (through Focused Maintenance) eliminate process defects. Therefore, the pillar prioritizes quality assurance over quality control (SINGH *et al.*, 2012).

4.2.4 Education & Training

Continuous improvement is only possible through continuous improvement of knowledge and skills of the people involved at the different organizational levels (Singh *et al*., 2012). For Netto (2008), this pillar is responsible for controlling the knowledge of everyone involved in TPM, operators, maintainers and leaders. Therefore, educating and training are fundamental to achieve the goals proposed in the TPM since the change in people's behavior, the increase of knowledge about equipment and the acquisition of new skills are highlighted within the program implementation (PALMEIRA, 2001).

Palmeira (2001) emphasizes that the planning of the Education and Training program, during the process of TPM implementation, must be done by setting up a matrix of skills and competencies for all involved in the organization. In this proposal, employees are grouped by related activities and all the skills and competences listed for the proper development of their

activities are compared with the current knowledge level. Therefore, all courses, training and retraining should be planned and carried out in accordance with the matrix (PALMEIRA, 2001).

The issues addressed by the Education and Training pillar, therefore, can be summarized as: transmission of knowledge about technologies, interpersonal skills and quality control, multiple employee qualification, alignment of stakeholders with organizational goals, and periodic assessment and updating of skills (AHUJA; KHAMBA, 2008). Thus, education and training aim to reduce losses due to human failures through empowerment, skills acquisition and self-esteem (NETTO, 2008).

4.2.5 Safety, health and environmental

Safety, health and environment represents the management front that aims at zero level of environmental and work accidents (NETTO, 2008). In other words, the purpose of this pillar is to create a safe working environment and surrounding area that is not damaged by the process or any procedure (Singh *et al.,* 2012). Ensuring the health of the company's employees, eliminating accidents, as well as preserving the environment, as well as legal and mandatory requirements, during the implementation of TPM contribute to ensure workers' motivation (PALMEIRA, 2001).

In addition to ensuring a safe and appropriate work environment, this pillar includes the elimination of injury and accident incidents and the provision of standard operating procedures (AHUJA; KHAMBA, 2012). That is, a greater importance for safety is given in the plant. The head of safety-related functions, in conjunction with maintenance management, aims to achieve zero accidents, zero health damage and zero fires (SINGH *et al*., 2012).

For Palmeira (2001), “the very process of TPM implementation through its various pillars, provides the improvement of safety in various aspects and forms”, since actions of Autonomous Maintenance, Planned Maintenance and Focused Maintenance increase the level of security in job.

4.2.6 Office TPM

For Ahuja and Khamba (2008), the issues addressed by the TPM office pillar are improving synergy between various business functions (sectors), removing procedural difficulties, addressing cost issues and 5S application in offices and work areas. Thus, TPM

office is the expansion of TPM use in all sectors of the organization whose objective is to reduce administrative losses through process optimization in speed, quality and reliability (NETTO, 2008).

TPM's activities cannot be restricted to the operation, since it can be expanded to administrative departments and support areas (PALMEIRA, 2001). For Singh *et al.* (2012), the TPM office should be used to improve the productivity and efficiency of administrative functions such as process or procedure automation. This pillar is developed based on the concepts of other pillars such as Focused Maintenance (specific improvements), Autonomous Maintenance and Education and Training (focused on administrative processes).

4.2.7 Development Management

Since the execution of equipment maintenance may be deficient due to lack of information or history of operation, a unified maintenance management for new equipment is essential (NETTO, 2008). Stimulating replication of learning from existing systems to new systems is one of TPM's development management approaches. This care contributed to achieve another focus of this pillar: minimum problems and timely operation in new equipment (AHUJA; KHAMBA, 2012).

Development management also encompasses maintenance improvement initiatives (AHUJA; KHAMBA, 2012). These activities occur even before the maintenance startup, which is why the pillar is also referred to as Initial Control (PALMEIRA, 2001), developed by the project team. Countermeasures are taken at different stages of the design of new equipment to prevent maintenance, cost reduction and operating standards (NAKAJIMA, 1988).

Similarly, the presentation of the content review results on ISO 55001 was structured in 2 subsections for better understanding and structuring.

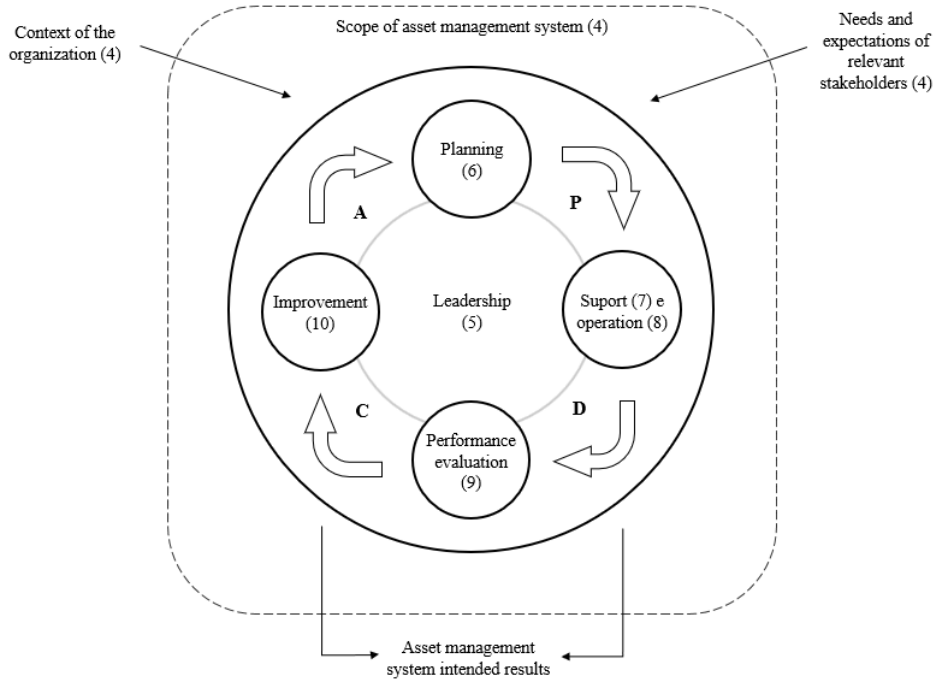
4.2.8 ISO 55001 Structure

The basis for the approach that underpins ISO standards management systems is based on the concept of the Plan-Do-Check-Act (PDCA) cycle. Thus, the structure of ISO 55001 in the PDCA cycle can be represented in a manner analogous to that presented to the requirements of the Quality Management System (QMS) in ISO 9001 and the Environmental Management System (AMS) in ISO 14001, as shown in Figure 3.

All management system standards (MSS) should, in principle, use consistent structure, text and common terminology to be easy to use and compatible with each other. This requirement is critical to providing a high-level, unified, agreed structure, identical core text, common terms, and basic definitions. A common approach to new MSS, and future revisions of existing standards, will increase the value of these standards to users (ISO, 2018).

According to the ISO (2018), this guideline is particularly useful for organizations opting for an integrated management system, also referred to as unique, that aims to meet the requirements of two or more MSS at the same time. Thus, the ISO 55001-based AMS enables integrated management with other standards, such as ISO 9001 and ISO 14001, as they share the same structure and sections as shown in Table 3.

Figure 3 – Representation of ISO 55001 structure in PDCA cycle



Source: Own authorship.

Table 3 – Structure of ISO 55001, ISO 9001 and ISO 14001 standards

N.	Section	N.	Section
1	Scope	6	Planning
2	Normative reference	7	Support
3	Terms and definitions	8	Operation
4	Context of the organization	9	Performance evaluation
5	Leadership	10	Improvement

Source: Own authorship.

4.2.9 Asset Management System Requirements

The ISO 55001 AMS requirements are organized to meet the PDCA cycle as shown in Figure 3. Thus, all sections together are critical to establishing, implementing, maintaining and improving the asset management system.

In section 1, Scope, the purpose of the standard is specified, where it is emphasized that the ISO 55000 series was designed for the management of physical assets, even though it is replicable to other types of assets. The Normative reference and Terms and definitions sections relate to ISO 55000, Asset Management - Overview, Principles and Terminologies, as an important complementary source of consultation as it is the ISO 55000 series standard that explains all terms and definitions.

Section 4, Context of the organization, requires the company's AMS to consider and understand the organization and the context involved. It also requires that you understand the needs and expectations of stakeholders. Based on this information, the standard ultimately requires you to determine the scope of the AMS.

Section 5 is unique to company leadership highlighting the company's commitment to the success of the AMS, the requirements for asset and role management policy, responsibilities and organizational authorities. It is in section 6, Planning, where the planning requirements for addressing risks and opportunities for the AMS and for achieving the AMS objectives are set out.

In section 7, Support, we present the necessary requirements for the implementation of the AMS in specific subsections: Resources, Competence, Awareness, Communication, Information requirements, Documented information. Section 8, Operation, highlights the

requirements of planning and operational control to implement the determined actions, change management and outsourcing.

The requirements for performance appraisal are presented in section 9, which highlights the need for the organization to monitor, measure, analyze and evaluate indicators, perform internal audits for AMS compliance with ISO 55001 and review by top management. Finally, section 10, Improvement calls for addressing identified nonconformities, preventive actions, and commitment to continuous system improvement.

4.2.10. Correlation of the themes

It is evident from the content review phase that TPM and AMS, although primarily dealing with physical assets, have different approaches. Nakajima (1988) proposed TPM as a breakthrough in the concept of productive maintenance as it incorporates economic efficiency and a total maintenance system and includes the autonomous maintenance pillar. With the recent introduction of the asset management system, according to ISO 55001, one more structure can be included in Nakajima's (1988) evolution of concepts, as shown in Table 4.

Although the AMS adds a management structure and alignment with the company's organizational objectives to the evolution of Nakajima's (1988) concepts, thus making asset maintenance activities more strategic, the autonomous maintenance (AM) pillar is not necessarily applied. In other words, ISO 55001 does not specify or exclude the need for AM for asset management. This definition will fit the organization during the planning stage, taking into consideration the context and its structure when addressing risks and opportunities for the AMS.

Table 4 – Relationship between asset management system, Total Productive Maintenance, Productive Maintenance and Preventive Maintenance

	Asset management system	Total Productive Maintenance features	Productive maintenance features	Preventive maintenance features
Economic efficiency (profitable preventive maintenance)	O	O	O	O
Total system (maintenance prevention, preventive maintenance and maintenance improvement)	O	O	O	
Autonomous maintenance by operators (small group activities)	-	O		
Management system structure and alignment with organizational objectives	O			

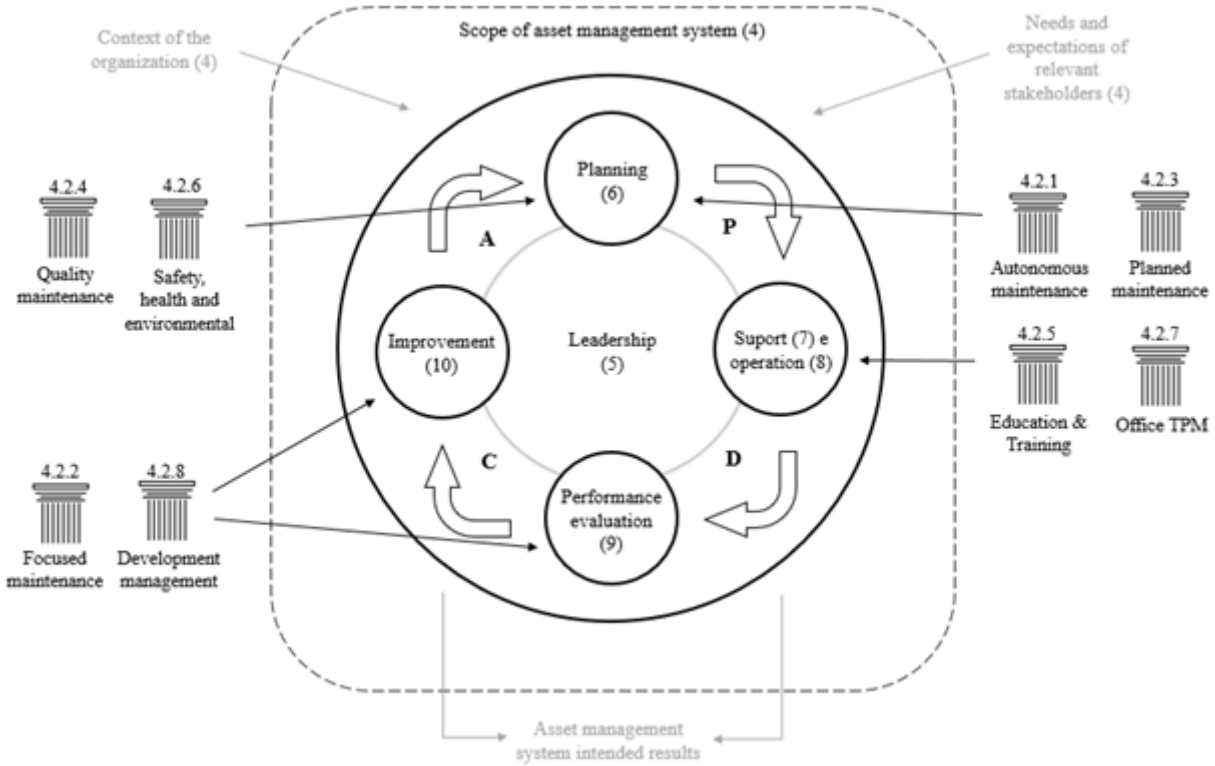
Source: Own authorship.

AMS can be said to broaden the TPM approach to physical assets. Rather than governing just one program focused on equipment maintenance with everyone's participation, the AMS proposes an asset-focused management system, the planning of which encompasses the entire life cycle of the asset and aims to contribute to the company's organizational strategic objectives. Therefore, answering the first question of the research, TPM can be an approach used during the implementation of an AMS, since it is a larger structure than TPM.

4.3 Interface Discussion

To answer the second and third research questioning, we used the representation of TPM interfaces with the AMS structure, as shown in Figure 4. In the representation of the interfaces, it is evident that the pillars that support the TPM program are related to the sections arranged in the structure of ISO 55001. The Autonomous Maintenance, Planned Maintenance and Quality Maintenance pillars address the requirements set out in section 6 (Planning) of the standard as these are processes and methods to be employed in the management of assets throughout their life cycle. Safety, Health & Environmental pillar, while broader than the standard, also relates to the same section as it identifies, assesses and addresses the risks associated with asset management.

Figure 4 – Representation of ISO 55001 structure in PDCA cycle with TPM pillars



Source: Own authorship

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Education & Training and Office TPM pillars, in turn, are associated with section 7 (Support). Education & training is what sustains and ensures the high performance of employees, which in the ISO 55001 standard has its requirements explained in the Competence subsection. The Office TPM also relates to section 7 as it is where requirements are divided into other subsections that address integration with other sectors and administrative activities, for example, Communication, Awareness, Documented information.

Finally, the Focused Maintenance and Development Management pillars relate to the Performance evaluation (9) and Improvement (10) sections. These pillars underpin the TPM program improvement activities, that is, they require data collection, performance appraisal,

historical and action propositions to address nonconformities or continually improve the structure of the TPM program.

Therefore, it is observed that there are interfaces between the TPM pillars and the structure of the ISO 55001 standard, as shown in Figure 4, thus answering the second question of the research. However, the scope of the TPM alone is not sufficient to meet all the requirements of the standard, according to the third research question. It is clear that sections such as Context of the organization (4) and Leadership (5), as well as specific subsections, e.g. outsourcing (8.3), internal Audit (9.2), and various requirements are not addressed by TPM.

Thus, it can be concluded that organizations with a consolidated TPM program will have fewer adjustments to meet all requirements for certification of an asset management system according to ISO 55001. On the other hand, a company which is seeking to deploy an AMS without any maintenance management model in place, can build on TPM as an approach to addressing lifecycle asset management maintenance requirements. However, further efforts will be needed to address points not met by TPM.

5. CONCLUSIONS

This paper aimed to discuss the interfaces between maintenance management based on the asset management system (AMS) in accordance with the requirements of ISO 55001 and Total Productive Maintenance (TPM).

To this end, the methodology was structured in three sections: Content review, Correlation of themes and Discussion of interfaces. In the first stage, the pillars that support the TPM program and the structure of the AMS were reviewed. In the second stage, the themes were correlated through comparison with other approaches in the evolution of maintenance. Finally, the interfaces between the themes were discussed through a representation of the TPM pillars related to the structure of the ISO 55001 standard.

The discussion on the theme showed that the TPM pillars support requirements and relate to sections of the AMS structure. However, the AMS is more comprehensive and the TPM is not sufficient for full service and understanding of the structure. Thus, it is up to the

organization's decision to apply TPM as an approach to addressing part of the AMS ISO 55001 requirements.

Therefore, this paper developed a qualitative exploratory study about the comparison of TPM with AMS. The results, achieved through a literature review, are general and theoretical in nature. The whole discussion answers the research questions and synthesizes considerations that may lead to future work. As a suggestion, a company case study using the TPM model for maintenance management prior to AMS implementation and certification, in accordance with ISO 55001, may reiterate and confirm the theoretical findings of this work.

This work contributes to the research field for several reasons. It provides a comprehensive theoretical review of two approaches applicable to maintenance management. Also, the article helps researchers and practitioners, especially those new to the field, to clarify concepts and interfaces between TPM and AMS.

Finally, it is expected that the results of this work contribute to the diffusion of the asset management system and boost new research, aiming to improve the maintenance management process, making companies more competitive.

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