
UNIVERSIDADE FEDERAL DE PERNAMBUCO
CENTRO DE TECNOLOGIA E GEOCIÊNCIAS
DEPARTAMENTO DE ENGENHARIA DE PRODUÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO

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# ENGINEERING ASSET MANAGEMENT: problem-solving models to support asset-intensive organisations in the regulatory and business performance contexts

Recife
2021

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Thesis presented to the Graduate Program in Production Engineering at the Federal University of Pernambuco, Technology and Geoscience Centre, as a partial requirement for obtaining the title of Doctor of Philosophy (PhD) in Production Engineering.

Research area: Production Management.

Supervisor: Prof. Dr. Ana Paula Cabral Seixas Costa

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2021

Catalogação na fonte
Bibliotecária Margareth Malta, CRB-4 / 1198

L732e Lima, Eliana Sangreman.
Engineering asset management: problem-solving models to support asset- intensive organisations in the regulatory and business performance contexts / Eliana Sangreman Lima. - 2021.
151 folhas, il., gráfs., tabs.

Orientadora: Profa. Dra. Ana Paula Cabral Seixas Costa.

Tese (Doutorado) – Universidade Federal de Pernambuco. CTG. Programa de Pós-Graduação em Engenharia de Produção, 2021.
Inclui Referências.
Texto em inglês.

1. Engenharia de Produção. 2. Gestão de ativos. 3. Gestão de riscos. 4. Regulação. 5. Método de decisão multicritério. 6. Indicadores de desempenho de ativos. 7. Indicadores de desempenho do negócio. I. Costa, Ana Paula Cabral Seixas (Orientadora). II. Título.

UFPE

658.5 CDD (22. ed.) BCTG/2021-103

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Approval date: 09/03/2021

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*To my son, Pedro Paulo, and my father, Lauro (in memoriam), who inspire me.*

## ACKNOWLEDGEMENTS

To my advisor, co-author and close friend, Dr Ana Paula Costa, for her prompt attention and great motivation. I am so lucky that our lives have been linked together both professionally and academically.

To my professors from the PPGEP, to whom I am grateful, especially Dr Adiel de Almeida for the academic encouragement.

To my co-authors and friends Ana Luiza de Lorena and Paul McMahon, for their tireless search for the best outcomes.

To my new friend Dr Ricardo Peculis from UOW who supported me in my stay in Australia, took me for nice afternoon coffees, telling funny stories, and discussing the theme of this thesis.

To my new friends from the PPGEP/UFPE who better know the difficulties of this so vast and full of challenges journey, especially Naiara Meireles and Ana Luiza de Lorena for sharing motivation.

To my long-time friends who encouraged me more than they can imagine. Especially, my thanks to Vilma Abadie and Elba Lins, who have been closely following my academic journey.

To my lovely family for the indispensable support.

*Without you, this personal fulfilment would have been much, much harder.*

*My sincere thanks to you all!*

*When you reach the top, keep climbing.*

*Zen Proverb*

## ABSTRACT

Asset-intensive organizations operate in competitive markets, deal with huge investments and handle numerous decisions, the consequences of which are significant for their permanence and growth in the Economic Sector in which they operate. Engineering Asset Management is responsible for the achievement of these objectives. Asset-intensive organisations that are strongly regulated need instruments to support decisions on implementing Asset Management (AM), while mitigating risk and contributing to the compliance with the regulatory framework of the Sector of the Economy. To solve this problem, this thesis proposes two managerial problem-solving models. The first is based on the experts' perception of the contribution of the implementation of Asset Management (AM) and Risk Management (RM) to meet the sector's regulatory requirements, without, however, analysing the regulatory framework in detail. The second is based on an in-depth analysis of the regulatory requirements. Their relevance goes to fill a gap in the literature to induce improvement and increase the level of maturity of AM, while contributing to the organization for its compliance with the regulatory framework. Both Models were applied to a Brazilian company in the Power Transmission Sector. Another management problem, experienced by asset-intensive organizations, is the need to understand 'how AM maturity impacts business performance', an issue that remains open, in the academic and business environments. Understanding how AM maturity impacts business, will make it possible for organizations to have greater confidence in AM investments that bring better returns to the business. In addition to the two models mentioned earlier, this research also proposes a managerial problem-solving model that offers insights into this understanding. The objective, therefore, is to offer a fundamental and useful way to show in advance "how the AM process relates to the business". The evidence of the relationship is the result of the analysis of case studies in different sectors of the economy, publicly available. In addition, the thesis also proposes an Integrated View of Engineering Asset Management (AM-IV) framework, which aims to offer a useful understanding of the complex multidimensional discipline of AM in a simplified way, and to contextualize the problem-solving models which are the object of this study. The main contributions of this study are: to fill a gap in the literature identifying priorities for the implementation of AM process whilst focusing on the regulatory framework of the Sector of the Economy; to contribute to the improvement of business performance, providing a path to the understanding of the impact of AM on business; and to encourage an increase in the efficiency of decision-making in AM.

Keywords: asset management; risk management; regulatory framework; multicriteria decision method; asset performance; business performance.

## RESUMO

Organizações intensivas em ativos operam em mercados competitivos, realizam grandes investimentos e lidam com inúmeras decisões, cujas consequências são significativas para sua permanência e crescimento, no Setor da Economia em que atuam. A Gestão de Ativos de Engenharia é responsável pelo cumprimento desses objetivos. Organizações intensivas em ativos e fortemente regulamentadas precisam de instrumentos que apoiem suas decisões na implementação do processo de Gestão de Ativos (AM), mitigando riscos e contribuindo para o cumprimento do marco regulatório do Setor da Economia. Para a solução deste problema, este estudo propõe dois modelos gerenciais conceituais. A primeira é baseada na percepção dos especialistas no que se refere à contribuição da implementação da Gestão de Ativos (AM) e Gestão de Riscos (RM) para o atendimento às exigências regulatórias do Setor, sem, entretanto, analisar o arcabouço regulatório em detalhes. A segunda é baseada em uma análise aprofundada dos requisitos regulatórios. A relevância da pesquisa está em preencher uma lacuna da literatura, quanto à indução da melhoria e aumento do nível de maturidade da AM, enquanto contribui com a organização para a sua conformidade com o *framework* Regulatório. Ambos os Modelos foram aplicados em uma empresa brasileira do Setor de Transmissão de Energia Elétrica. Outro problema vivenciado pelas organizações intensivas em ativos está na necessidade de entender 'como a maturidade em AM impacta no desempenho dos negócios', uma questão que ainda permanece em aberto, nos ambientes acadêmico e empresarial. Entendendo-se como a maturidade em AM impacta nos negócios, será possível às organizações terem maior confiança em investimentos em AM que tragam melhores retornos ao negócio. Além dos dois modelos gerenciais explicitados anteriormente, esta pesquisa também propõe um modelo gerencial de solução de problemas que oferece *insights* para este entendimento. O objetivo, portanto, é oferecer um caminho fundamental e útil para, primeiramente, evidenciar "como o processo de AM se relaciona com o negócio". A evidência do relacionamento é resultado da análise de estudos de caso em diferentes setores da economia, disponibilizados publicamente. A tese propõe, ainda, uma Visão Integrada da Gestão de Ativos de Engenharia (AM-IV), que oferece, de forma simplificada, uma compreensão útil da disciplina multidimensional que é a AM, e contextualiza os modelos de solução de problemas que são objeto deste estudo. As principais contribuições deste estudo são: preencher um gap da literatura ao identificar prioridades na implantação do processo de AM, com foco no arcabouço regulatório do Setor da Economia em análise; favorecer a melhoria do desempenho do negócio

ao prover um caminho para a compreensão do impacto da AM no negócio; bem como encorajar o aumento da eficiência do processo de decisão em AM.

Palavras-chave: gestão de ativos; gestão de riscos; regulação; método de decisão multicritério; indicadores de desempenho de ativos; indicadores de desempenho do negócio.

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## LIST OF ACRONYMS

| | |
|---|---|
| ALC | Asset Life Cycle |
| AM | Asset Management |
| AMBP | Asset Management and Business Performance Relationship Model |
| AMC | Asset Management Council |
| AM-IV | Engineering Asset Management Integrated View |
| AMMM | Asset Management Maturity Model |
| AM-RoM | Regulation-Oriented Model for Asset Management |
| AMS | Asset Management System |
| ANEEL | *Agência Nacional de Energia Elétrica* (National Electric Power Agency) |
| API | Asset Performance Indicators |
| BEETE | Brazilian Electric Energy Transmission Enterprise |
| BSC | Balance Scorecard |
| BSI | British Standard Institution |
| CAPEX | Capital Expenditure |
| DM | Decision Maker |
| EAM | Engineering Asset Management |
| ELECTRE | *Elimination Et Choix Traduisant la Réalité* |
| GFMAM | The Global Forum on Maintenance & Asset Management |
| IAM | The Institute of Asset Management |
| ISO | International Standards Organization |
| KPI | Key Performance Indicator |
| MCDM | Multi-Criteria Decision Method |
| MPA | Maintenance Performance Assessment |
| MPM | Maintenance Performance Measurement |
| PAS | Publicly Available Specification |
| PDCA | Plan-Do-Check-Act Model |
| PROMETHEE | Preference Ranking Organisation Method for Enrichment of Evaluations |
| PRORET | *Procedimentos de Regulação Tarifária* |
| RM | Risk Management |

**CONTENTS**

# 1 INTRODUCTION

Asset-intensive organisations operate in various sectors of the economy, such as energy, transport, mining and agribusiness, among others, and deal with a huge investment. These organisations usually have a permanent challenge, which is to ensure the effective management of their assets so that they deliver greater value to their stakeholders. They cope with inherently complex processes, involving specialized areas, multidisciplinary expertise, and different levels of commitment. In addition, when managing their assets, these organisations handle a great amount of information and make decisions that have an influence on their competitiveness or even their survival. In addition to all this complexity, infrastructure organisations are strongly regulated while being required to have higher business performance, and being socially, economically, and environmentally sustainable. Therefore, it is to be expected that in the face of so many challenges these organisations have a lot to deal with.

Asset Management (AM), despite being a subject of academic research and an object of appreciable business interest for over 20 years, has not resolved all the challenges that it has faced. Thus, according to Davis (201-?), the subject remains current for academic review and advancement, as well as for business as a pragmatic, hands-on subject.

The interest to academia is because there are still unanswered questions about this matter. Some of these unanswered questions are discussed in this thesis. It is of interest to business because of the necessity for organisations to be sustainable, which requires “avoiding adverse long-term impacts to the organization from short-term decisions” (IAM; BSI, 2008), a problem not easy to solve, not even for a large asset-intensive organisation. Furthermore, the effectiveness of the decisions in AM is an indispensable condition for making organisations more valuable, and, in this sense, consolidated management models are powerful tools. If the models are effectively designed for a given scenario, that is, if adequately adapted to the needs of organisations, they increase the chances of these organisations being better structured to achieve their strategic objectives. According to Birkinshaw and Goddard (2009), distinct management models can, by themselves, be an important competitive factor.

AM is a complex multidisciplinary cross-functional field (GFMAM, 2014; IAM, 2015). The framework of AM theory consists of several components: concepts, principles, standards, models, methods, disciplines, assessment instruments, and strategies. An understanding of the way in which the various components relate to each other results in a deeper understanding of the AM environment.

Due to this complexity, an integrated view, in which the components of the AM are differentiated and classified according to their purpose, is useful as it provides a broad view of the AM environment and gives insights into which component is best suited to a given problem.

Asset management, as a process, provides the multifunctional and integrated view needed to further the efficiency and effectiveness of assets (ISO, 2014a). Asset Management, as a discipline, involves multiple components that encompass the internal and external contexts of its boundaries, as well as an understanding of how these components are related to each other. Understanding this dynamic can contribute to the knowledge of the various possibilities in the designing of problem-solving support tools, which are necessary for the effective control and governance of assets by organisations.

## 1.1 THE AM PROBLEM-SOLVING CONTEXTUALISATION

Many organisations realise the importance of having structured AM and RM processes to guarantee the maximization of the value of their assets and the minimization of risks. Due to human, financial and material restrictions, organisations need to decide on the implementation of AM&RM practices in order to obtain a better assessment of their assets and, at the same time, to comply with the regulations of the sector in which they operate. Structuring the AM process properly is essential to prioritize investments and focus efforts on the most critical assets. This allows the organisation to centre on the benefits that will bring the greatest gains, such as better financial performance, better investment decisions, managed risk, demonstrated social responsibility, demonstrated compliance, improved reputation, improved organisational sustainability, and greater efficiency and effectiveness (ISO, 2014a). However, some managers do not have the necessary experience in the discipline of AM or have difficulty in implementing it, mainly due to the critical nature of the decisions (IAM, 2015), as they usually involve a significant amount of capital.

To know what AM and RM requirements that should be implemented in the organisation to promote conformance with the sector regulation is one of the many necessities asset-intensive organisation deal with. In terms of understanding the regulatory context, two situations can be considered by the organisation when dealing with this issue. One of them requires only a general comprehension of the regulatory framework of the sector in which the organization performs, while a much deeper analysis is needed for the other one, as it requires detailing of the regulatory framework.

Another important aspect, according to The Institute of Asset Management (IAM) (IAM, 2016) is that "Organisations are increasingly recognising AM as a discipline that has relevance and significant potential for improving performance". It is extremely useful that asset-intensive organisations manage their assets in accordance with the best practices, as well as understand 'how AM maturity reflects on business performance'. An approach to be pursued in addressing this open question is the necessity to first understand 'how the AM process relates to business performance'. Investments in AM are known to be significant for asset-intensive companies. Thus, if this issue is well understood, it will be possible to focus the investments on AM processes that are relevant to a business context. In other words, to have adequate information to prioritize which AM requirements will support better the business goals.

The solution to the two problems contextualised above can be addressed by different approaches. This study presents three problem-solving approaches, two of them designed for the strategic context of regulation and one designed for the strategic context of business performance.

## 1.2 THE RESEARCH DESIGN

The research definition (which describes the research questions, primary and secondary objectives, and the theoretical and practical justification), the research type, and the research context compose the research design. A synthesis of the research design, jointly with the thesis structure (Item 1.3), is shown in Figure 1.

### 1.2.1 The Research Definition

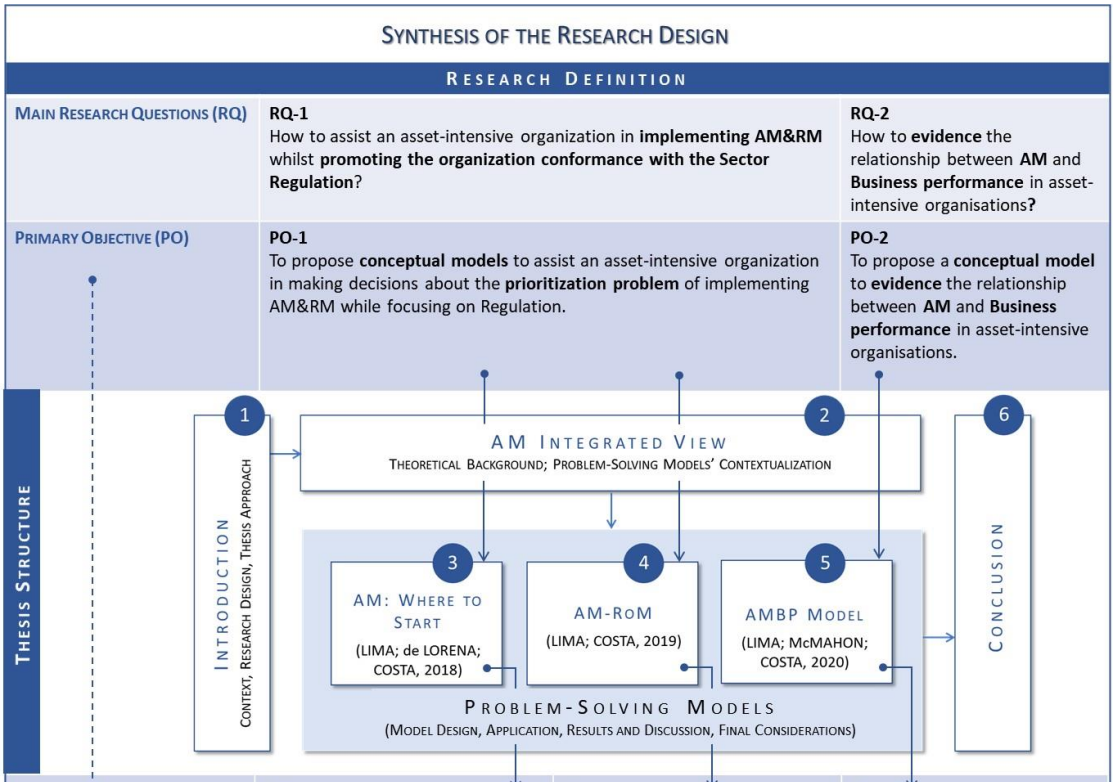
For each of the two problems discussed in Item 1.1, there is a research question. To the first research question, there is the main objective with three secondary objectives. To the second research question, there is the main objective with two secondary objectives. The elements of the research definition are detailed next.

#### 1.2.1.1 Research questions, primary and secondary objectives

**Research question 1**: How to assist an asset-intensive organisation in implementing AM and RM whilst promoting the organisation conformance with the Sector Regulation?

> Primary Objective: To propose conceptual models to assist an asset-intensive organisation in making decisions about the prioritization problem of implementing AM and RM while focusing on Regulation.

Figure 1 - Synthesis of the Research Design and Thesis Approach




| RESEARCH TYPE | | | |
|---|---|---|---|
| RESEARCH APPLICATION | Applied research | Applied research | Fundamental/ theoretical research |
| TECHNICAL PROCEDURES | Conceptual/theoretical Modelling | Conceptual/theoretical Modelling | Conceptual/theoretical |
| **RESEARCH CONTEXT** | | | |
| PROBLEM DESCRIPTION | AM and RM Implementation focusing on Regulation | AM and RM Implementation focusing on Regulation | Evidencing Links between AM and Business Performance |
| STRATEGIC CONTEXT | Regulatory Context | Regulatory Context | Business Performance |
| PURPOSE | AM Decision-Making | AM Decision-Making | Increased Knowledge |
| PROBLEM TYPE | Managerial | Managerial | Managerial |
| SOLUTION APPROACH | Based on a general understanding of the regulatory framework | Based on an in depth analysis of the regulatory framework and on strategic directions | Published Case Studies based |
| PROPOSED MODEL | Asset Management: Where to Start?<br>(AM: Where to Start Model) | Asset Management Regulation oriented Model<br>(AM-RoM) | Asset Management and Business Performance Relationship<br>(AMBP Model) |
| APPLIED TO | Energy Transmission Company (Real company) | Energy Transmission Company (Real company) | Various Sectors of the Economy (Case Studies) |

Source: The author (2021)

Secondary Objectives:

**a)** To explore the prioritization problem with the support of a conceptual model, based on a general understanding of the Sector Regulatory Framework.

**b)** To deepen understanding of the prioritization problem with the support of a conceptual model, based on strategic directions and on an in-depth analysis of the Sector Regulatory Framework.

**c)** To test the conceptual models for their feasibility in an asset-intensive organisation.

**Research question 2**: How to evidence the relationship between AM and business performance in asset-intensive organisations?

Primary Objective: To propose a conceptual model to evidence the relationship between AM and business performance in asset-intensive organisations.

Secondary Objectives:

**a)** To establish the premises for the relationship between AM and Business Performance, based on the literature.

**b)** To evidence the relationship between AM and business performance in asset-intensive organisations with the support of a conceptual model, based on AM case studies of different sectors of the economy and on the established premises.

#### 1.2.1.2 Theoretical and practical justification

The literature addresses some conceptual models in AM. Examples of internationally known models are: The IAM Conceptual Model for Asset Management (IAM, 2015) and Asset Capability Concept Model (AMC, 2014). Despite the availability of these specialized models in the AM context, there is no prescription to improve the AM process by focusing on the regulatory framework compliance. The first primary objective of this thesis is theoretically justified for being designed to be prescriptive in explaining how to make decisions in implementing AM focusing on Risk and on the sector regulation, minimizing this gap in academia regarding the regulatory approach (LIMA; COSTA, 2019).

An open issue in the literature is the understanding of 'how AM relates to business performance'. Knowing this is a fundamental and useful way to discover ‘how the maturity of organisations in AM impacts the performance of the business’, an issue that remains up to date in the academic and business environments (LIMA; McMAHON; COSTA, 2020). The second primary objective is theoretically justified because it minimizes this gap in the academia.

The primary objectives are relevant in practice because they aim to provide actions that:

a) contribute to the strategic alignment of the AM process with the business strategy, aiming to improve the results of the AM process and, consequently, of the organisation;
b) subsidize the implementation of action plans, identifying priority actions for AM in the organisational context;
c) integrate the various multifunctional areas of the organisation, towards a common objective;
d) identify priorities to provide AM with effective control and governance of assets, essential to obtain value for the organisation (ISO, 2014a);
e) meet the expectations of stakeholders, by adding value to assets based on compliance with international standards in AM and compliance with regulation, as well as contributing to improving business performance;
f) encourage the increase of the efficiency in decision-making in AM with the prioritization of essential requirements to the organisational context;
g) meet the requirement of "continuous improvement" demanded by ISO 55000: 2014 (ISO, 2014a).
h) contribute to the economic aspect, suggesting important models for the improvement of performance of asset-intensive companies.

### 1.2.2 The Research Type

Regarding the research application's type, the first and second problem-solving approaches are both 'applied research' as they deal with a solution for a real problem faced by an asset-intensive company. As defined by Nallaperumal (2013), applied research is the one whose goal is "to find a solution for an immediate problem facing a society or an industrial / business organization…. applied research concentrates on discovering a solution for some pressing practical problem".

For the third problem-solving approach, the research application's type is classified as 'fundamental or theoretical research', that "is focused towards formulation of theories that may have a broad base of applications either at present or for the future which adds more material to the already existing organized body of scientific knowledge" (NALLAPERUMAL, 2013). This study focuses on a theory about the relationship between AM and business, not much explored in academia yet.

Regarding technical procedures, the first and second problem-solving approaches are classified simultaneously as conceptual/theoretical and modelling research. Conceptual/theoretical because, according to Filippini's typology (NAKANO, 2012), they are a conceptual discussion based on literature, bibliographic reviews and conceptual models. Modelling, because of the use of mathematical techniques to describe the functioning of a system or part of a productive system. In this case, the mathematical techniques are embedded in the Multi-Criteria Decision Method (MCDM), a branch of the Operation Research discipline, whose foundation is the development of support tools for optimal decision-making.

Based on the same typology, the third problem-solving approach is classified as a conceptual/theoretical research, because it concentrates on quality analysis of bibliographic and documentary sources.

### 1.2.3 The Research Context

For asset-intensive companies, the strategic context can be of different aspects, such as sustainability, compliance with regulation, and business performance. In this thesis, the problem discussed in the first and second problem-solving approaches characterizes the problem description as being 'Asset Management (AM) and Risk Management (RM) implementation, focusing on the regulatory context'. In this context, the regulation comprises all the standards and rules that are established by the regulatory agencies, and the aim is usually to keep costs and revenues under control, while requiring service of high reliability and efficiency (CATRINU; NORDGÅRD, 2011).

For the third problem-solving approach, the problem description is about the 'evidencing links between Asset Management and Business Performance' and the strategic context is the business performance context. This context comprises the "disciplines, processes and tools that enable organizations to optimize the way they execute business strategy" (ECKERSON, 2010), including financial and non-financial objectives to pursue growth and ensure competitiveness.

Regarding the organisation's purposes, for example: assessment of maturity; decision-making support; increased knowledge about an AM issue; assessment of the asset and AM performance, among others, the solutions were designed to support the organisations in solving the problems contextualised in Item 1.1. The first and second problem-solving approaches are characterized as being an AM decision-making purpose, and the third problem-solving approach as being a purpose of increasing knowledge in AM.

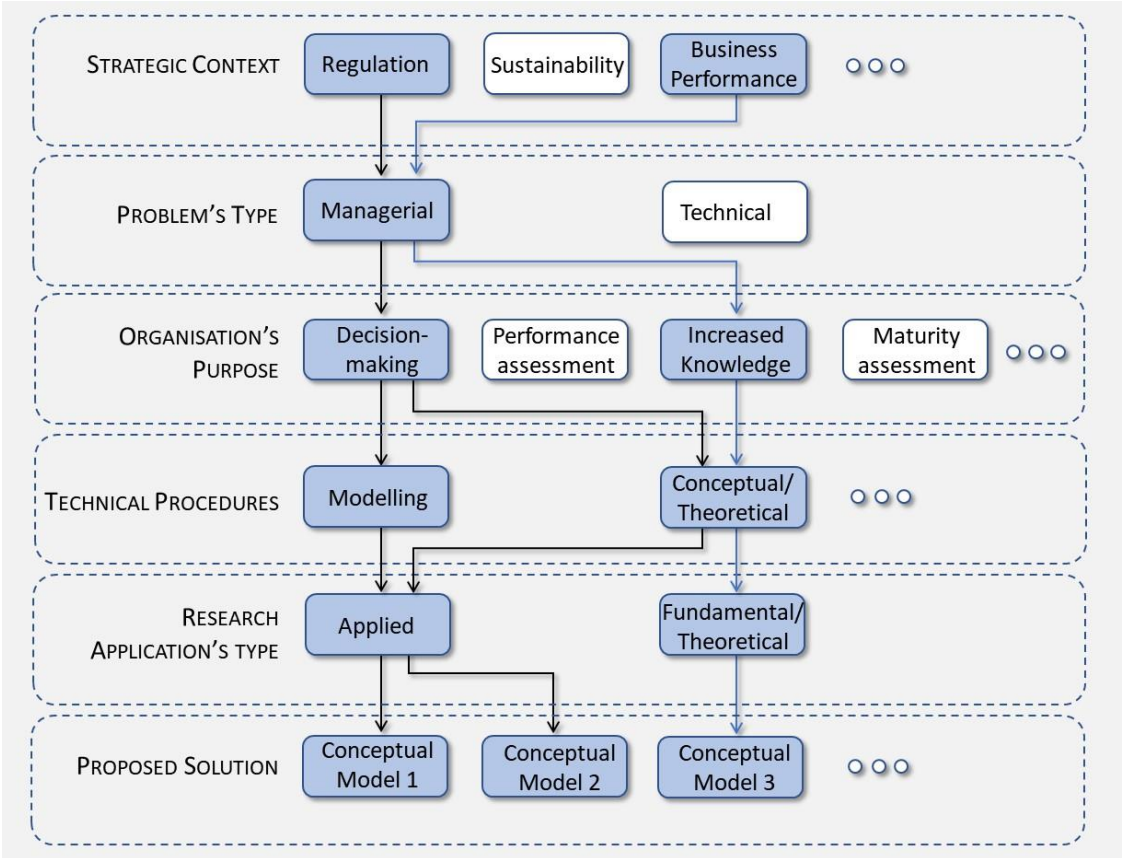
For each of the strategic contexts, due to the many individual issues experienced by organisations, two types of problems may emerge, namely technical and managerial. The

problem's type is managerial for all of the three problem-solving approaches, as they do not deal with technical issues, such as the performance of the assets, but only with typical managerial questions. The type of AM problems is better discussed in Item 2.1.1.

The solution approach must be adherent to all of the above definitions. The first solution is based on a general understanding of the sector regulatory framework. The second solution is based on an in-depth analysis of the sector regulatory framework and on strategic directions. The third solution is based on evidence from published AM case studies.

The main characteristics of the problem-solving approaches, discussed in this section and in the previous one, are highlighted in the six hierarchical layers of Figure 2: the strategic context, the problem's type, the organisation's purpose, the technical procedures, the research application's type, and the proposed solution. It is important to notice that, for each problem, there is not a one-size-fits-all solution, but one that is appropriate to the problem being faced.

Figure 2 - The problem-solving methodological approaches




Source: The author (2021)

An analysis of the problem-solving approaches leads to the following considerations regarding Figure 2: the first problem of managerial type arose in the strategic regulatory context.

Two solutions of an applied nature, using modelling and conceptual procedures are proposed to assist the company to make decisions about which AM and risk requirements should be implemented with priority, whilst focusing on regulation. The second problem, also managerial type, arose in the strategic context of business performance. A solution of a theoretical nature using a conceptual procedure is proposed to help asset-intensive companies to improve their knowledge about how AM relates to business performance, aiming to understand, in the future, how the AM maturity impact on business.

## 1.3 THE THESIS STRUCTURE

The thesis is developed in a multi-paper approach, in which three papers on the subject of Engineering Asset Management are presented in adapted versions. The thesis structure, jointly with the research design, is shown in Figure 1.

The papers propose the problem-solving models which methodological approaches are highlighted in Figure 2. The models are contextualized by the **Engineering Asset Management Integrated View – AM-IV**, described in Chapter 2**.**

The first paper (LIMA; de LORENA; COSTA, 2018) proposes a problem-solving model developed to assist intensive-assets companies in solving a problem in the 'regulatory strategic context': the **AM Where to Start Model** (Chapter 3). In this model, the standards ISO 55001:2014 (asset management) and ISO 31000:2018 (risk management guidelines) are analysed aiming to identify requirements for implementing the asset management process whilst promoting the organisation conformance with the regulation of the Power Transmission System. The methodology involves the use of PROMETHEE II (Preference Ranking Organisation Method for Enrichment of Evaluations) and an application in a large company in the Power Transmission Sector. The resulting ranking of requirements based on experts' perceptions and on the aggregation of the decision-maker's preferences, offers a prioritization of such requirements. The results are satisfactory in guiding the organisation as to where to start the implementation of the asset management process, based on a general understanding of the sector regulatory framework.

The second paper (LIMA; COSTA, 2019) also proposes a problem-solving model developed to support asset-intensive companies in solving a problem in the 'regulatory strategic context': The **Regulation-Oriented Model for Asset Management – AM-RoM** (Chapter 4). This model also embodies a joint analysis of ISO 31000:2018 and ISO 55001:2014. The AM-RoM encompasses the PROMETHEE II multi-criteria decision method to rank the most critical

requirements, based on experts' knowledge. Its relevance goes to the contribution to organisations in the process of inducing improvement and increasing the maturity level of the AM process, while being in compliance with the regulatory framework. The validation of the AM-RoM was performed in a Brazilian company in the Transmission Sector. The main difference from the previous model is that it is based on an in-depth analysis of the sector's regulation and on the aggregation of the expert's knowledge.

The third paper (LIMA; McMAHON; COSTA, 2020) proposes a problem-solving model developed to assist asset-intensive companies in increasing their knowledge on an AM issue, related to the 'business performance strategic context': the **Asset Management and Business Performance Relationship Model – AMBP Model**. The model offers enablers supporting the organisations to make better decisions in infrastructure investments, through the construction of a relationship map between AM key-processes, asset performance indicators (API) and business key performance indicators (KPI). The relationship between these three elements is a result of the analysis of case studies in different sectors of the economy, publicly available on AM specialized sites or AM conference proceedings. Knowing 'how AM process relates to Business Performance', the aim of this paper, is a fundamental and helpful path to understand 'how AM maturity impacts on business performance', an issue that remains up to date in both the academic and business environments.

Given this Introduction, the remaining of this document is organized as follows: Chapter 2 provides the basis for conceptual models, which are the essence of the thesis, and describes the **Engineering Asset Management Integrated View (AM-IV)**; Chapter 3 describes the **AM: Where to Start** Model; Chapter 4 describes the **Asset Management Regulation oriented Model - AM-RoM**; Chapter 5 describes the **Asset Management and Business Performance Relationship Model - AMBP Model**; and Chapter 6 discusses and concludes the thesis.

# 2 THEORETICAL BACKGROUND IN THE CONTEXT OF AN ENGINEERING INTEGRATED VIEW OF AM

This chapter briefly introduces the Engineering Asset Management (EAM) concept. Also, it proposes an Integrated View of Engineering Asset Management – AM-IV, which aims to contextualize the conceptual models, the object of the next chapters.

## 2.1 AN INTRODUCTION TO ENGINEERING ASSET MANAGEMENT

**Engineering asset management** is defined as "the total management of physical, as opposed to financial, assets" (AMADI-ECHENDU et al., 2010). The authors complete the definition noticing that "engineering assets have a financial dimension that reflects their economic value, and the management of this value is an important part of overall engineering asset management". In this thesis, the terms 'asset management (AM)' and 'engineering asset management (EAM)' are used interchangeably.

Asset-intensive companies, like the ones in the energy, mining and agrobusiness sectors, just to exemplify, operate in competitive markets, deal with huge investments, and handle numerous decisions daily, the consequences of which are significant for their permanence and growth in their sector of the economy. To improve their performance and obtain better returns, these companies must focus on the efficiency of Asset Management (AM) investments that are relevant to a business context.

AM is, by nature, inherently complex. It is responsible for supporting organisations in the achievement of a greater objective, which is the effective decision-making and governance of the whole asset life cycle (ALC). The responsibility for the asset life cycle management includes "organising, planning and controlling the acquisition, use, care, refurbishment, and/or disposal of physical assets in order to optimise their service delivery potential and to minimise related risks and costs over their entire life" (FROLOV et al., 2009). Besides that, it deals with an intense flow of information, which involves functionalities from a variety of business areas, specialized knowledge, and many levels of commitment (LIMA; de LORENA; COSTA, 2018). Although this responsibility has an inherent degree of considerable difficulty, the complexity of AM is mainly because it incorporates a diverse approach and way of thinking, in addition to providing transformation, and organisational and cultural alignment (IAM, 2015).

AM is a quite sophisticated multidisciplinary oriented process, due to the involvement of a broad range of disciplines (LIN et al., 2007) and requires ongoing and strategic attention

by the organisation. AM is based on four fundamentals or principles that can be translated into continuous actions such as: focus on the value the asset can offer to the organisation (Value); translation of strategic intent into technical, economic and financial decisions (Alignment); conducting of the implementation, operation and improvement of AM in the organisation (Leadership); evidence that the assets will achieve their essential objective (Assurance). As the guardian of these principles, AM ensures that value is realised from assets. The better the organisation incorporates the fundamentals in its management system, the easiest it adapts to changes, and the better it can achieve and maintain higher performance (GFMAM, 2014; ISO, 2014a).

Effective management of the assets, which is the essence of the 'Asset Management – AM' discipline, presupposes the balancing of costs, risks, opportunities and performance benefits (ISO, 2014a), while preventing or mitigating the loss of resources, such as time and money, and possible damage to the company's reputation. AM improves the performance of the assets of organisations aiming to achieve benefits for business, such as compliance, sustainability, competitiveness, and effectiveness. In addition, it enhances the institution's credibility and public recognition.

AM encompasses asset value strategies and policies, balancing financial and operational performance, and risk (ISO, 2014a). It also includes standards, assessment methodologies, conceptual models among other dimensions.

The concept of value is of fundamental importance for understanding the purpose of AM in the context of business. Value can be tangible or intangible, financial or non-financial, and includes consideration of risk at all stage of the asset life. According to Lima, McMahon and Costa (2020), it is expected that the more mature an organisation is in managing its assets, the more value it can extract from them.

As stated by IAM (2015), "Each organisation has to determine what it considers value to be and choose how to manage its assets to derive best total value". Value can take many meanings depending on the organisation's purpose and the stakeholder's expectations (AMADI-ECHENDU et al., 2010; ISO, 2014a; SRINIVASAN and PARLIKAD, 2017; WOODHOUSE, 2018). There are many expectations among the various stakeholders and, consequently, different perceptions of asset value and the benefits that can be achieved by the asset life cycle management. Some examples of stakeholders' expectations include financial returns for investors, compliance with safety regulations, quality measures, value for customers and rewards for employees.

AM can afford many benefits, which are impacted by the decision-making process (ISO, 2014a) such as: improved financial performance; informed asset investment decisions; managed risk; improved services and outputs; demonstrated social responsibility; demonstrated compliance; enhanced reputation; improved organisational sustainability; improved efficiency and effectiveness. On the other hand, AM deals with many degrees of complexity of problems due to the intrinsic nature of its object of action, the assets. The AM problem aspects are discussed next.

### 2.1.1 AM Problems

AM addresses a vast range of AM problems, which require decisions related to extracting greater value from assets. Two types of problems regarding the level of competencies are managerial and technical.

AM technical problems and decisions deal with technical requirements that are intrinsic to the asset performance, such as: development, operation and maintenance of the physical infrastructure, equipment and facilities; incorporation of new technologies; reliability, maintainability, availability, uncertainties/vulnerability reduction; asset renewal; determining critical spares; resolution of safety issues. These are technical attributes that affect the cost of a system's economic lifecycle and its usefulness.

AM managerial problems and decisions are those related to the asset management in a systemic view and more adherent to those related to the business strategies, including: investment budgeting and strategic planning issues related to the organisation’s goals; asset maintenance budget; capital investments’ priorities; compliance with new legal requirements and other restrictions; implementation of an AM System; AM training; AM certification; exploring the impact of AM on business; AM maturity evaluation; competence requirements; construction of models and frameworks for specific AM needs.

For both problem types, technical and managerial, the type of application of research can be theoretical – formulation of a theory that explains an issue and may have a broad base of applications either at present or in the future – or applied – concentrated on discovering a solution for some pressing practical problem (NALLAPERUMAL, 2013).

Depending on the characteristics of the AM problem and the organisation culture and knowledge, the problem-solving process can be assisted by specific models, methodologies, and methods, and may be followed by managerial or technical decision-making as well. In this case, an AM decision-making process should be established.

AM decisions are often competing interests. For example, an organisation must decide between “asset utilisation/performance versus asset care (maintenance), capital investment cost versus operating expenditures, or short-term benefits versus long-term sustainability” (IAM, 2015). It is important to consider that regardless of whether the problem has technical or managerial competence, “asset management decisions are actually business decisions, so the need to make financially optimized decisions” (GREEMAN, S., 2019).

It is an important part of AM, to understand how asset decisions are made (ISO, 2014c). The next item briefly discusses the AM Decision-Making Process. The quality of knowledge as derived from the experience, values, information in context, and insight, will affect the reliability and quality of decision making (IAM, 2015). Another aspect is the criticality in defining the authority to make decisions in AM (actual or delegated) (AMC, 2014).

### 2.1.2 The AM Decision-Making Process

Effective decision-making in AM is essential in organisations responsible for infrastructure assets, which are excessively expensive in investments, operation and maintenance. According to IAM (2015), what makes AM different from other disciplines beyond the focus on the ALC is its approach to decision making.

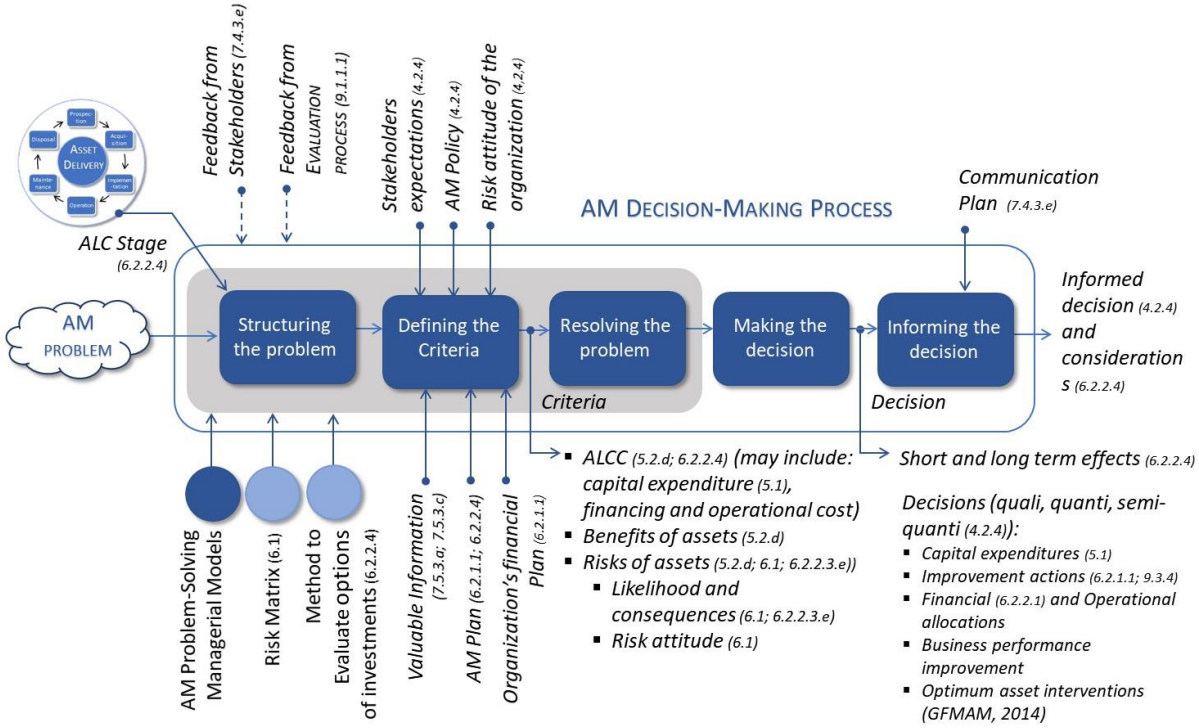
In a broad view, the AM decision-making approach leads necessarily to the discussion of many aspects, such as: AM types of decision (SUN; FIDGE; MA, 2008); AM decision-making method and criteria (ISO, 2014b), AM decision-making process (GFMAM, 2014; ISO, 2014c; TRINDADE et al., 2019); quality data and trusted information for AM decision-making (BROUS; JANSSEN; HERDER, 2016; POLENGHI A. et al, 2019); technology for AM decision-making (HAIDER, 2011); AM decision-making support models (LIMA; de LORENA; COSTA, 2018; LIMA; COSTA, 2019). All of these aspects are equally important and, depending on the decision to be made in the context of AM, it may be necessary to deepen one or more aspects.

Based on ISO55002 (ISO, 2014c), the AM Decision-Making Process is illustrated in a simplified way in Figure 3[1]. Some of the main requirements to be considered are: the internal and external stakeholder’s needs and perceptions; the AM Policy; quality information (completeness, accuracy, consistency, relevancy, timeliness); risk perception; the AM plan; the organisation’s financial plan; the feedback from stakeholders; and the feedback from the evaluation process. It is important to note the feedback from ‘Resolving the problem’ to

[1] The itemization in Figure 3 is from ISO (2014c).

'Defining the criteria' and from 'Defining the criteria' and 'Structuring the problem'. Even though it is not shown, this feedback is intrinsic to a decision-making process. Although clear, regarding to 'what', AM standards do not spell out 'how' decisions should be made, nor what instruments should be considered to support those decisions.

Figure 3 - AM Decision-Making Process




Source: Based on ISO 55002:2014 (2014c)

The standard recommends that the decision criteria be relevant to their importance and complexity in setting priorities and resolving conflicting requirements. According to ISO (2014c), "decision-making criteria should be appropriate to the importance and complexity of the decisions being made" and "used to evaluate competing options to meet asset management objectives and develop asset management plans". Also, the criteria should support quantitative, semi-quantitative or qualitative decisions. The output of the decision-making process is for stakeholders "to be informed about the decisions that can affect them and might need to provide input into decisions that can have an impact on them" (ISO, 2014c).

Given this brief introduction of Engineering Asset Management, in order to facilitate the understanding of the main elements which constitute its scope, and at the same time contextualize the conceptual models that are the object of the thesis, it is proposed the Engineering Integrated View of Asset Management described next.

## 2.2 ENGINEERING ASSET MANAGEMENT INTEGRATED VIEW – AM-IV

The **EAM Integrated View (AM-IV)** is a framework designed in three layers that brings together the main dimensions of AM, with a focus on the procedural-methodological aspect. AM-IV aims to offer the benefits of functional integration, by proposing in a simplified way a useful understanding of the complex disciplinarity of AM and, in particular, to contextualize the conceptual models which are the object of this study. It is important to note that other aspects are equally important, such as technological, human and cultural, although these are not in the scope of the framework.

AM takes place when it is instantiated to a specific business context, which in turn is instantiated to a specific Sector of the Economy, where intensive companies operate. These two elements – business and the sector of the economy, the AM-IV middle and external layers respectively – constitute the externality of AM. The internality of AM is represented by its main dimensions as models, standards, and processes, among others. The interrelations between the AM dimensions are an important aspect of the framework, as an understanding of the way in which the various components relate to each other strengthens the understanding of the AM environment. The AM-IV framework is shown in Figure 4 and is detailed throughout this chapter.

### 2.2.1 AM-IV External and Middle Layers

In this section, the following topics will be depicted: the sectors of the economy, business performance, business strategy and the AM related standards.

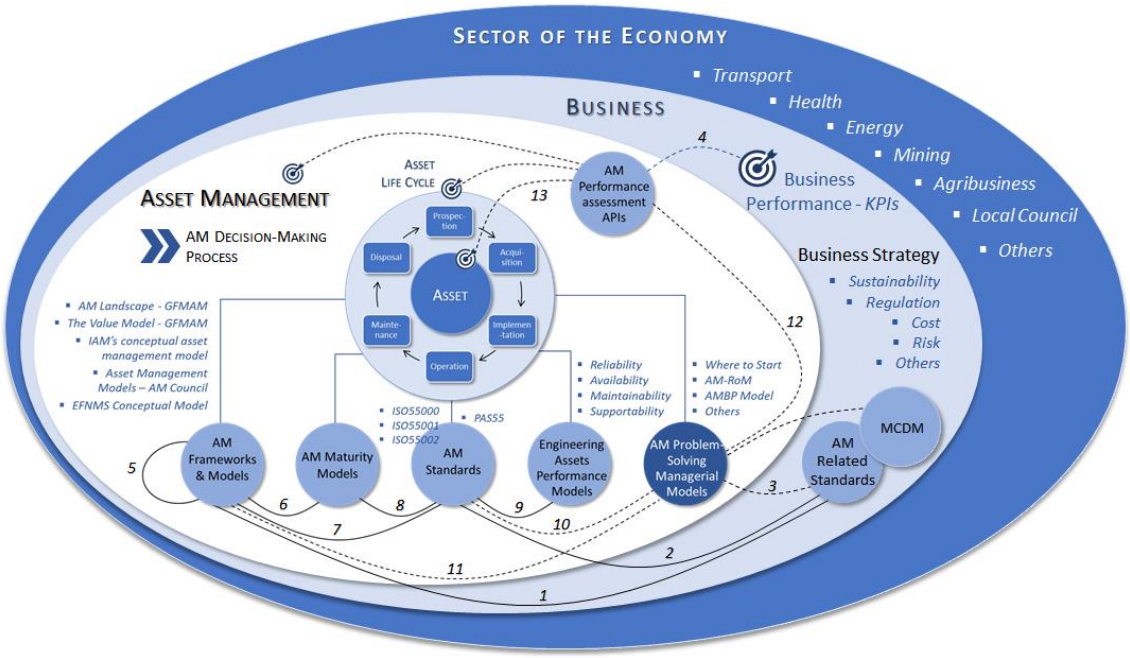
#### 2.2.1.1 Sectors of the Economy

The sectors of the economy represent the external layer of the AM-IV. AM, if properly applied, should improve the performance of an intensive-asset organisation which, in turn, should favour the sector of the economy in which it operates. Each sector of the economy has many peculiarities, regarding their assets, such as: necessary investments; regulatory attributes; definition of asset value; operation and maintenance requirements; criteria for decision-making; and strategies. Examples of sectors of the economy are transport, health, energy, mining, agribusiness, among others.

Some of the businesses operating in these sectors, depending on the strategy, need large amounts of capital to keep their industrial park updated to slow depreciation. As a result, there is a need for efficient asset management and an adequate business performance evaluation

system. The type of industry sectors clearly influences the type of Business Key Performance Indicators - KPIs (LIMA; McMAHON; COSTA, 2020), shown in the middle layer of the AM-IV, and described in the next section.

Figure 4 - EAM Integrated View (AM-IV)




Source: The author (2021)

### 2.2.1.2 Business Performance

Business performance management is essential to foster growth and organisational competitiveness. As a measure of performance, key performance indicators (KPIs) are used to track and manage the business. KPIs vary according to the competitive environment, the business lifecycle, the organisation's strategies, among many other factors. Examples of KPIs are: Financial/profitability; customer satisfaction; quality of products and services; productivity; flexibility; innovation; environmental responsibility/safety; effectiveness; efficiency; learning, competitiveness; social responsibility; employee performance; compliance with the sector regulation.

Expanding the analysis to intangible assets, which is not the focus of the thesis, but only to contribute to the understanding of the relationship between the sector of the economy and KPIs, for sectors that include service industries, the creation of value may require more focus on KPIs such as quality, for example. Other sectors, such as mines, which deal with many tangible assets with significant capital expenditure, financial and safety KPIs should be a focus.

Innovation KPI may be required for an organisation to adapt to changes imposed by internal or external factors (LIMA; McMAHON; COSTA, 2020).

#### 2.2.1.3 Business Strategy

Defining the business is essential because it makes it clear who the target customers are and what the organisation's core business is. The exercise of thinking about core business makes it explicit to the organisation where it should foster its competencies to better position itself in the sector. From the internal and external analysis of the organisation, it is possible to make a detailed diagnosis of how much the company is prepared, or not, to face the opportunities or threats of the environment. It makes it possible to choose appropriate strategies, based on a critical assessment of these environments. As generic examples of themes associated with strategies, there are: Sustainability, regulation, cost, risk. The definition of the strategy is fundamental to guide the requirements of a decision support system. As the main business strategies of the scope of the thesis are Regulation and Risk, they are summarized next.

**Regulation** is defined as the intervention of the State in the country's economic and social order, by controlling the provision of services through entities that execute and supervise them, ensuring the universalization of their services with the purpose to protect the public interest. As a business strategy, it also aims at maintaining the economic and financial balance of contracts between principal and agent through the definition of tariff policies, which is one of the most relevant aspects of the Regulation, considering the need to ensure profitability for investors and economic viability for consumers (ANEEL, 2018b).

Although countries have different regulatory practices, the goal is generally to keep the organisation's costs and revenues under control, in the face of required highly reliable and efficient services (CATRINU; NORDGÅRD, 2011). In Brazil, the electricity sector is regulated and supervised by the *Agência Nacional de Energia Elétrica* - ANEEL, an autarchy under a special regime, linked to the Ministry of Mines and Energy, whose mission is to provide advantageous conditions for the development of the power market, balancing interests between agents and benefits for society (ANEEL, 2018a).

Another business strategy is **Risk** which is defined by ISO (2018) as the effect, positive or negative, of uncertainties on the organisation's objectives, which result in opportunities or threats. Every activity involves risk at any level, so organisations of all sectors and sizes must manage them to define the best strategies and make the most appropriate decisions. According to ISO (2018), managing risk contributes to the improvement of management systems, and is an

attribution of governance and leadership. In the case of the Asset Management System, risk and opportunity management maximizes the value of the asset (ISO, 2014b).

Some important elements about the relevant management areas, directly or indirectly related to AM, are summarized below.

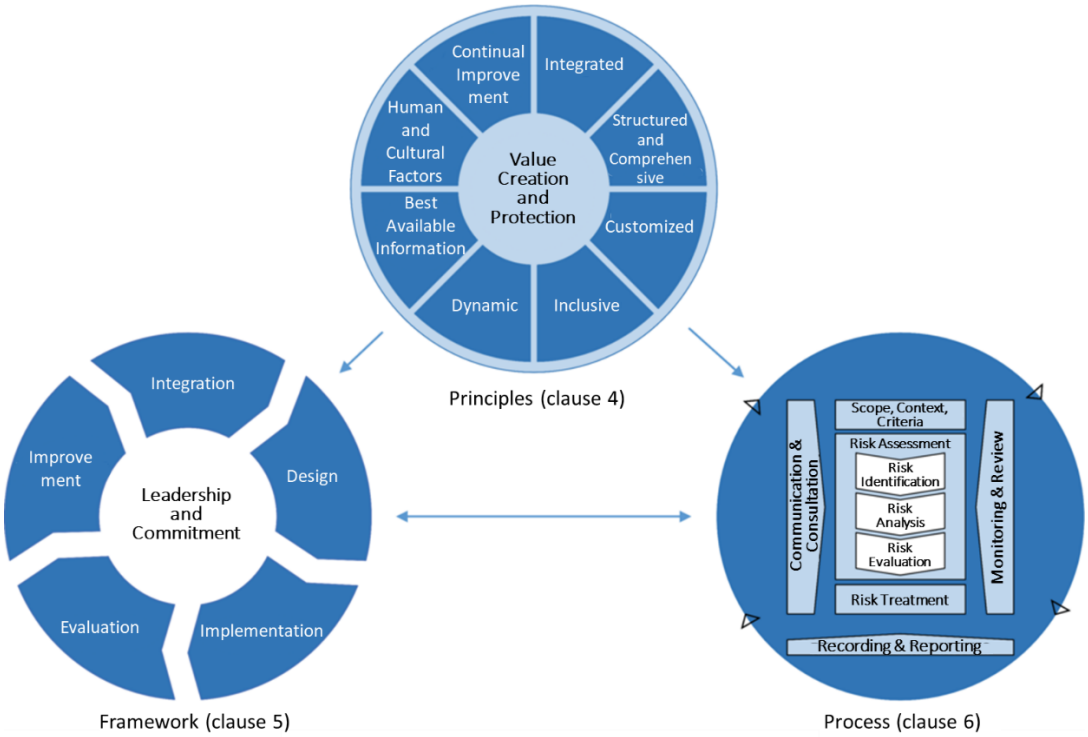
#### 2.2.1.4 AM related standards

Several standards from specific topics are related to AM, as can be seen in ISO (2014c) and GFMAM (2014). Some examples of relevant management areas related to AM are: data and information; risk; quality; environment; configuration; project; systems and software engineering; sustainable development; inspection; auditing; outsourcing; infrastructure; Systems Engineering Management; supply chain. Among these, the risk area is particularly important in the construction of decision support models which are the objective of this research (Chapters 3 and 4), therefore ISO 31000: 2018 standard (ISO, 2018) is summarized next.

According to ISO (2009), risk management framework is described as the "set of components that provide the foundations and organisational arrangements for designing, implementing, monitoring, reviewing and continually improving risk management (RM) throughout the organization", while the risk management process is stated as a "systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk".

The Risk Management Framework (Leadership & commitment; Integration; Design; Implementation; Evaluation; Improvement) and Risk Management Process (Communication and consultation; Scope, Context, Criteria; Risk assessment; Monitoring and review; and Recording and reporting), outlined by ISO (2018), together with the principles (integration, structured and comprehensive, customized, inclusive, dynamic, uses the best available information, considers human and cultural factors, practices continual improvement) are aligned with the asset management system (ISO, 2014b). The first aims to design, implement, monitor, review, and continually improve risk management across the organisation. The latter offers a systematic application of management policies, procedures and practices, responsible for communication, consultancy, context analysis, assessment, treatment, monitoring and review of risk (ISO, 2009). Figure 5 shows the principles, framework and process of ISO 31000:2018 (ISO, 2018).

Figure 5 - ISO 31000:2018 – Principles, framework and process




Source: Adapted from ISO (2018)

### 2.2.2 AM-IV Internal Layer

As can be seen in Figure 4, in addition to the assets and the Asset Life Cycle (ALC), the following dimensions are part of the internal environment of AM: AM Standards; AM Frameworks & Models; AM Maturity Models; AM Performance assessment (APIs) Models; Engineering Asset Performance Models; and AM Problem-solving Managerial Models. These dimensions are presented next. The dimension of AM Problem-solving Managerial Models is intentionally highlighted in Figure 4, as it is also the focus of this research.

The relevance of the relationships among the dimensions in the internal layer is shown in Table 2 and the relationships between the dimensions in the internal layer with the dimensions in the middle and external layers are shown in Table 1. The relation's numbers refer to the numbers of the linking lines in Figure 4.

#### 2.2.2.1 The Asset and the asset life cycle

An asset is defined by ISO Standard 55000, as something of potential or real value, for an organisation (ISO, 2014a). According to the specificities of the organisation and the importance attributed by its stakeholders, the value varies and can be tangible or intangible, financial, or non-financial. To extract greater value from assets, the organisation must define, in

advance, what it considers value and establish the most appropriate means to manage it (IAM, 2015). Notwithstanding this broader concept of assets, in this thesis, the focus is on engineering or physical assets.

Table 1 - Relationship between the dimensions of the AM-IV layers

| RELATION | DIMENSION | | RELEVANCE |
|---|---|---|---|
| 1 | AM Frameworks and Models | AM Related Standards | Some frameworks and models refer to standards of different areas related to AM. |
| 2 | AM Standards | AM Related Standards | ISO 5500X makes explicit reference to the standards of several areas related to AM. |
| 3 | AM Problem-Solving Managerial Models | AM Related Standards | Decision support models that also focus on standards from other areas related to AM, such as RM. |
| 4 | AM Performance Assessment Models | Business Performance (KPIs) | Decision-making support models in AM which offer enablers about the impact of APIs on business KPIs. |

Source: The author (2021)

Table 2 - Relationship among the dimension of the internal layer of AM-IV

| RELATION | DIMENSION | | RELEVANCE |
|---|---|---|---|
| 5 | AM Frameworks and Models | AM Frameworks and Models | Some models, such as the IAM and AMC models uses the GFMAM subjects.<br>The 39 GFMAM's subjects impact on the other GFMAM subjects (Figure 7). |
| 6 | AM Frameworks and Models | AM Maturity Models | Some AM management frameworks and models incorporate AMMM |
| 7 | AM Frameworks and Models | AM Standards | Frameworks and Models make explicit reference to ISO 5500X and are adherent. |
| 8 | AM Maturity Models | AM Standards | Some AMMM are designed to assess adherence to ISO AMS 5500X |
| 9 | AM Standards | Engineering Asset Models | Technical models support the decision to realise the value of assets. |
| 10 | AM Problem-Solving Managerial Models | AM Standards | Decision support models focusing on the requirements of ISO 55001. |
| 11 | AM Problem-Solving Managerial Models | AM Frameworks and Models | Problem-solving managerial models that use elements from other frameworks and models, such as the 39 GFMAM subjects. |
| 12 | AM Problem-Solving Managerial Models | AM Performance Assessment Models | Problem-solving managerial models that focus on the performance of the business. |
| 13 | AM Performance Assessment Models | Asset, ALC | Asset performance assessment models can encompass the asset itself, the ALC process and AM as a whole. |

Source: The author (2021)

Due to the participation of a wide range of disciplines involving the entire asset lifecycle (ALC), the AM process has an intrinsic complexity (LIN et al., 2007) and requires the organisation's continuous and strategic attention. The whole asset life cycle depends on the type of asset being managed and, in general, comprises the phases from the initial identification of requirements or opportunities, acquisition/creation, operation and maintenance, until the disposal of the asset (GFMAM, 2014).

According to Woodhouse (2018), although only the processes that directly impact assets can be assessed for their cost-effectiveness in terms of resulting performance, the support activities or management system contribute indirectly to realise value from assets, improving the efficiency and effectiveness of those processes.

It is important to highlight that most publications from the industry focus on the core AM processes that evolved from the maintenance aspects of infrastructure intensive industries. The maintenance process affects all aspects of business effectiveness and risk, safety, environment, energy efficiency, product cost, quality and customer service. As companies have developed further, the maintenance function has been enveloped into AM as a part of the asset lifecycle (ATTWATER et al., 2014; CHEMWENO; PINTELON; VAN HORENBEEK, 2013; El-AKRUTI; DWIGHT; ZHANG, 2013).

Having introduced the asset and the ALC, an overview of the AM standards is discussed in the next item. The AM standards present "common practices that can be applied to the broadest range of assets, in the broadest range of organizations, across the broadest range of cultures" (ISO, 2014a).

#### 2.2.2.2 The AM Standards

AM Standards offer a structured way to manage assets, with the aim of supporting organisations to be competitive and sustainable. They are: PAS 55-1:2008 (Specification for the optimized management of physical assets) (IAM; BSI, 2008a); PAS55-2:2008 (Guidelines for the application of PAS 55-1) (IAM; BSI, 2008b); ISO 55000: 2014 (Overview, principles and terminology) (ISO, 2014a); ISO 55001: 2014 (Management systems - Requirements) (ISO 2014b); ISO 55002: 2014 (Management systems - Guidelines for the application of ISO 55001: 2014) (ISO 2014c) and ISO 55010: 2019 (Guidance on the alignment of financial and non-financial functions in asset management) (ISO, 2019). Of these, ISO 55001: 2014 (ISO, 2014b) is the focus of the thesis and some of its most important aspects are summarized next.

ISO 55001 (ISO, 2014b) proposes to structure the essential information of the assets by consolidating AM and knowledge practices through an Asset Management System – AMS.

According to ISO (2014b), the implementation of AMS allows the organisation to achieve its objectives through the control and effective governance of its assets, maximizing their value over time. The requirements for the AMS: Context of the organisation, Leadership, Planning, Support, Operation, Performance Evaluation, and Improvement, in a clear reference to the traditional PDCA Management Model (Plan, Do, Check, Action), as illustrated in Figure 6[2]. Besides that, ISO (2014b) states that the AMS "can be applied to all types of assets and by all types and sizes of organizations" from the most diverse sectors of the economy.

Figure 6 - Asset Management System (AMS)


Source: adapted from Dunn (2015).

The AMS helps the organisation to achieve its goals through efficient and effective control of its assets, maximizing value over time (ISO, 2014b). It is important to note that, despite the AMS's own name referring to 'System', it is, in fact, a 'Management Model' of AM, which characteristics are adherent to the definition of a 'conceptual model' by GFMAM (2014): "A conceptual model describes, at the highest level: the key aspects of asset management, how these interact with each other and how they link to the overall corporate objectives and business plan".

The organisations are subjected to internal and external environments, both of which are a constant source of uncertainties (ISO, 2018), hence the concern of ISO55001 about risk. When

[2] The numbers in Figure 6 refer to the ISO 55001: 2014 itemization (ISO 2014b).

ISO 31000:2018 (ISO, 2018) is integrated into ISO 55001: 2014 (ISO, 2014b), it is expected that the organisation can maximize its assets' value with minimum risk.

The Asset Management standards are basic references for the various AM frameworks and models available in the literature. The most relevant ones are considered in the categories that belong to the AM-IV Internal Layer and are the subject of the next items.

#### 2.2.2.3 AM Frameworks and Models

The AM Models and Frameworks dimension involves models from several entities specialized in AM, or from the literature. The objective is the management of AM, normally adhering to the AMS of ISO55001 Standard. Examples of relevant frameworks/models are AM Landscape (GFMAM, 2014); The Value Model (GFMAM, 2016); IAM's conceptual asset management model (IAM, 2015); Asset Management Models – AM Council (AMC, 2014). Table 3 shows the objective of each of these models.

Table 3 - The main AM Models and Frameworks

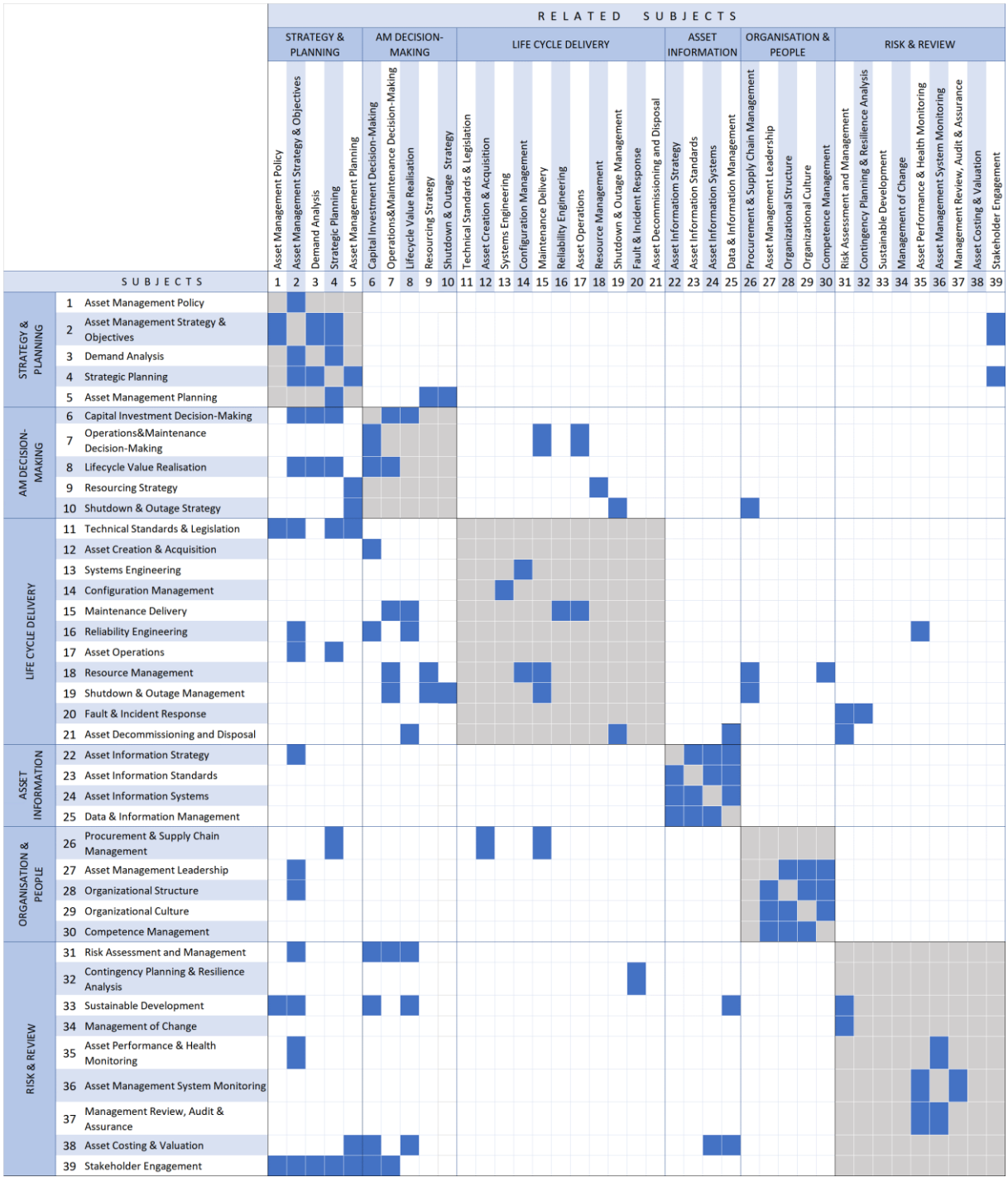
| MODEL/FRAMEWORK | OBJECTIVE | SOURCE |
|---|---|---|
| The Landscape Framework | To "facilitate the exchange and alignment of maintenance and asset management knowledge and practices". | GFMAM (2014) |
| The Value Model | To describe "how asset management can bring value to an organisation and its stakeholders". | GFMAM (2016) |
| The IAM's Conceptual Asset Management Model | To "provide an appreciation of asset management: what is; what it can achieve; the scope of the discipline and a description of the underlying concepts and philosophy". | IAM (2015) |
| Asset Management Concept Model | To "serve as a conceptual framework from which the foundational elements of asset management can be identified, documented and implemented". | AMC (2014) |
| Asset Management System Model | To "illustrate the key elements of an asset management system and how they inter-relate". | AMC (2014) |
| Organisational System Model | To "depict the typical components of an organisation's management system and how they inter-relate". | AMC (2014) |
| Capability Delivery Model | To "document a typical set of processes that can be used to: provide guidance for the application of" an AM system; "develop and implement" an AM system capability; and "develop and implement an asset capability (solutions) for an organisation". | AMC (2014) |

Source: The author (2021)

One of these models/frameworks is of a special interest to the purpose of the thesis. It is the Landscape Framework (GFMAM, 2014). Particularly, the interest is on the 39 asset management subjects, that together describe the scope of asset management. GFMAM (2014)

categorizes them into six groups of subjects: Strategic & Planning, AM Decision-Making, Asset Information, Risk & Review, Asset Delivery, and Organisation & People. According to IAM (2015), “the importance of individual Subjects to a specific organisation will depend on its organisational purpose and context”. Figure 7 shows how the 39 AM subjects, which are the basis for the AM Problem-solving Managerial Model detailed in Chapter 5, relate to each other.

Figure 7 - AM Process Subjects Relationship

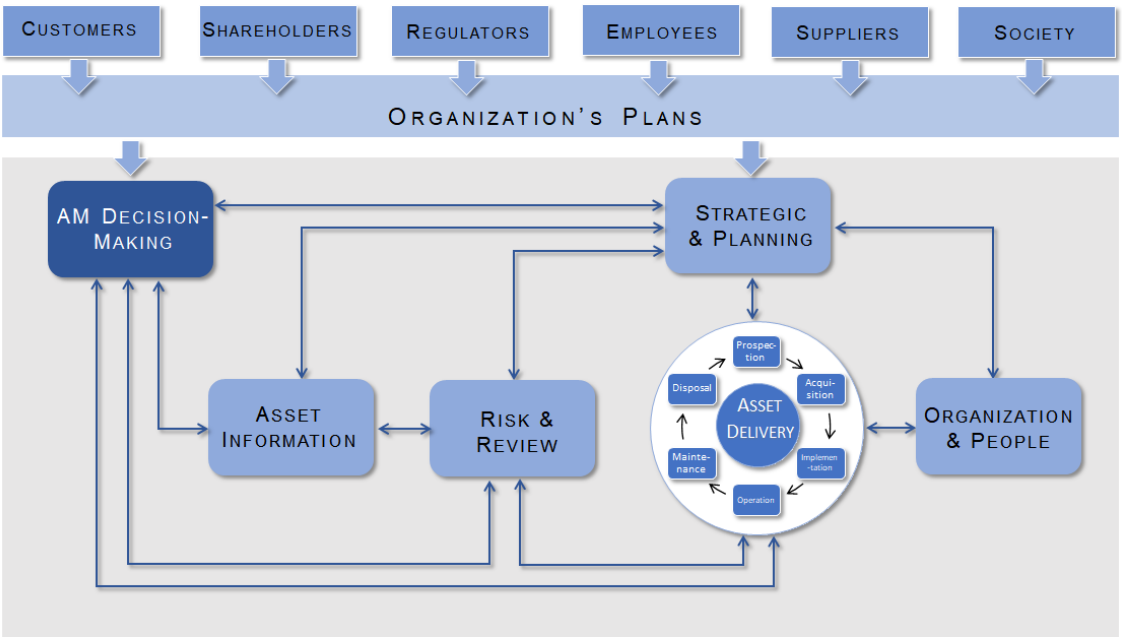



Source of data: based on GFMAM (2014)

Note that the subject of one group relates to the subjects of the same group and to the other groups as well. This reinforces the idea that they "can not be treated as self-standing and independent and it is not possible to understand asset management properly without addressing them all as a holistic integrated body of knowledge" (GFMAM, 2014).

Based on Figure 7, Figure 8 summarizes the relations among the 6 subject groups, established by the Global Forum, that are fundamental in the context of AM. In summary, the stakeholder expectations, materialized in the Organisation's Plans, are the input for the Strategy and Plans subject group. This group issues the AM Plan that is carried out by the Asset Delivery subject group, with structured resources by the Organisation & People subject group. Decisions are made at all stages of the Asset Life Cycle, considering information about the asset, which is the responsibility of the Asset Information subject group, and risk analysis, which is managed by the Risk & Review subject group. This group is also responsible for auditing processes.

Figure 8 - AM Process Subjects Groups




Source of data: based on GFMAM (2014)

The context of AM is quite complex and multidimensional. In addition, decisions in asset-intensive organisations are numerous and present at all levels of the organisation. For each problem, there is a multitude of models to support them, which depend on the organisation, its context, its culture, its knowledge, among other variables.

#### 2.2.2.4 AM Maturity Models

The AM Maturity Models dimensions are those whose objective is to support the decision regarding the improvement of the AM process. In these models, starting from a structure in successive levels and criteria, it is possible to establish a maturity metric. The literature is extensive on this topic. To exemplify them, some references are cited: Chemweno, Pintelon and Van Horenbeek (2013); Dennis et al. (2017); GFMAM (2015); IAM (2016); Volker, Van der Lei and Ligtvoet (2011); Zeb, Froese and Vanier (2013). Table 4 shows examples of Asset Management Maturity Model (AMMM) and its objectives.

Table 4 - AM Maturity Models (Examples)

| AMMM | OBJECTIVE | SOURCE |
|---|---|---|
| A generic asset maintenance maturity model | A "structured guide to maintenance process maturity. The proposed model aims at assessing the maintenance decision making capabilities within organisations". | Chemweno, Pintelon and Horenbeek (2013) |
| Asset performance management maturity model | A "systematic approach to analyzing an organization's asset management processes, technologies, capabilities, and systems". | Dennis et al., 2017 |
| Asset Management Maturity Scale and Guidance | An "introduction to the subject of Asset Management maturity and how it can be defined, scaled and recognised". | IAM, 2016 |
| Infrastructure Management Maturity Matrix ($IM^3$) | The $IM^3$ distinguishes five maturity levels from ad hoc to optimised, and seven asset management dimensions: information management, internal coordination, external coordination, market approach, risk management, processes & roles, and culture & leadership. | Volker, Van der Lei and Ligtvoet (2011) |
| An Integrated Asset Management Capability Maturity Model | A "capability maturity model which addresses all three outlined dimensions": temporal, organisational and spatial dimensions. | Laue et al. (2014) |
| Infrastructure Management Process Maturity Model (IM-PMM) | To benchmark the current level of maturity of work processes and communications in the domain of infrastructure management. | Zeb, Froese, and Vanier (2013) |
| Property Asset Management Capability Model-OGC (PAMCAM-OGC) | "An on-line self-assessment tool that enables government organisations to measure their corporate property asset management capability and identify areas for improvement" | Gov.UK (2014) |

Source: The author (2021)

It is essential to measure how mature the organisation is in managing its assets to realise value (GFMAM, 2015). So, the concept of maturity and the way this maturity can be evaluated through an AMMM, must be considered as well. AMMM usually defines the levels of the organisation's AM process as: 0 - innocent, 1 - aware, 2 - developing, 3 - competent, 4 -

optimizing and 5 – excellent; or other variations (LAUE et al., 2014; MAHMOOD et al., 2015; VOLKER; VAN DER LEI; LIGTVOET, 2011; ZEB; FROESE; VANIER, 2013). The context of the organisation and its approach to AM impact on what is regarded as ‘competent’ or ‘excellent’ for the organisation (IAM, 2015).

Through an enhanced understanding of the constraints in AM plan execution (SCHUMAN; BRENT, 2005) and a better understanding of the AM processes involved (BROWN; SPARE, 2004), it is reasonable to assume that AM maturity contributes somehow to business performance, although enhanced AM maturity does not necessarily mean high business performance (KERSLEY; SHARP, 2014; WOODHOUSE, 2011). In other words, although many organisations use an AMMM to improve the AM process, how the AM Maturity impacts on business depends upon the context of the organisation and is still the focus of studies (SHAH; McMANN; BORTHWICK, 2017).

#### 2.2.2.5 AM Performance Assessment Models

There is a vast academic literature on AM, however, most of the publications are restricted to the 'asset maintenance function’, the origin of the discipline, later encapsulated in a broader view of AM (ATTWATER el al., 2014; CHEMWENO; PINTELON; HORENBEEK, 2013; El-AKRUTI; DWIGHT; ZHANG, 2013). Therefore, the AM Performance Assessment dimension incorporates models, some of them dealing specifically with the ‘maintenance’ aspect, such as: a multi-criteria hierarchical framework for Maintenance Performance Measurement (MPM) (PARIDA; CHATTOPADHYAY, 2007); a multi-criteria hierarchical framework for Maintenance Performance Assessment (MPA) (PARIDA, 2008). Others consider asset performance in a broader view of its lifecycle, such as: performance measurement for asset management systems (ATTWATER et al., 2014); a performance measurement for infrastructure assets (BITRE, 2017).

#### 2.2.2.6 Engineering Asset Performance Models

The Models of the Engineering Asset Performance dimension are intended to support the decision in AM, with regard to technical attributes that affect the economic lifecycle of assets, such as: reliability, maintainability, availability and security. The models that support decisions of asset maintenance and operation are included in this category. In the literature, there are numerous available models such as: ‘a model of inspection of a protection system in which the inspection outcome provides imperfect information of the state of the system’ (CAVALCANTE; SCARF; BERRADE, 2019); ‘a multi-criteria model to support the definition

of opportunistic maintenance policy' (LOPES; CAVALCANTE, 2015); 'a simulation to optimize the periodic inspections to minimize the expected costs of maintenance' (MARSARO; CAVALCANTE, 2017).

Although extremely important for the efficient management of engineering assets, these types of technical models are not the subject of the thesis. The main object is the models that deal with managerial aspects related to AM, such as those addressed in the next item.

#### 2.2.2.7 AM Problem-solving Managerial Models

In the AM Problem-solving Managerial Models dimension, the models aim to support the solution of AM problems, regarding managerial problems as those exemplified in Item 2.1.1, some in a more extensive fashion, such as: 'investment budgeting and strategic planning issues related to the organisation's goals' (SCHNEIDER et al., 2006); a 'value-based decision making process for asset intensive organisations' (TRINDADE et al., 2019); a 'generic split decision-making process model' that "addresses both the basic AM decision-making process and the specific needs of the AM decision context" (SUM; FIDGE; MA, 2008); others, with a more concentrated focus on a certain business strategy, such as: a 'structural framework for defining the performance metrics perspectives' (ATTWATER et al., 2014); a 'methodology to implement AM and RM with focus on a wide view of Regulation' (LIMA; de LORENA; COSTA, 2018); a 'model to implement AM and RM with focus on an in-depth analysis of the regulation' (LIMA; COSTA, 2019); a 'model to evidence the relationship between asset management and business performance' (LIMA; McMAHON; COSTA, 2020); a 'model to link physical asset management to sustainability performance' (MALETIČ et al., 2018). Also, related to managerial decisions involving technical aspects of AM such as 'the use of a simplified numerical decision-making methodology to support maintenance-related decisions' (BURNETT & VLOK, 2014).

Having seen the main types of AM frameworks and models, the conceptual models that are the object of the thesis are contextualized in the AM-IV, as depicted in the next item.

## 2.3 THE CONTEXTUALISATION OF THE CONCEPTUAL MODELS IN THE AM-IV

As described previously, the Integrated View of AM (AM-IV) offers a framework in which the main components of AM are categorized in various dimensions, based on their purpose. The next sections aim to summarize which AM-IV dimensions are used in the development of the three conceptual models, that are object of the thesis.

### 2.3.1 The AM: Where to Start Model in the context of the AM-IV

In the context of AM-IV (Figure 4) the 'AM: Where to Start?' Model belongs to the ‘AM Problem-solving Managerial Models' dimension. It also encompasses other dimensions and elements of AM as shown in Table 5.

Table 5 - AM: Where to Start Model in the context of AM-IV

| LAYER | DIMENSION | ELEMENT |
|---|---|---|
| External | Sector of the Economy | Energy |
| Middle | Business Strategy | Regulation<br>Risk Management |
| | AM Related-Standards | ISO31000 |
| Internal | AM Standards | ISO55001 |
| | AM Problem-solving Managerial Models | AM: Where to Start Model |

Source: The author (2021)

Both the elements Regulation and Risk Management (RM) of the business strategy dimension, in the middle layer, belong to the problem definition the ‘AM: Where to Start’ Model was developed to solve. The first, because it involves the decision scenario to which the organisation needs to be in conformance; the second, for being part of the organisation's strategy that requires RM to be instantiated to the AM process.

As for the Energy element, the model was developed to meet the needs of an organisation in the Energy sector, which requires high availability and reliability from its assets, in order to comply with regulatory requirements, avoiding fines and enabling fair remuneration.

With regard to the ISO55000 and ISO31000 Standards, internationally recognized and considered fundamental to the construction of the model, the first, because it is the main standard related to AM, used by companies that wish to implement, improve or certify such a process; the second, for supporting the organisation's strategy with regard to the management of risks in the AM process. The model deepens the connection between the ISO55001 (AM Standards dimension) and ISO31000 (AM Related-Standards dimension) elements, identifying the common and complementary requirements of the two standards.

### 2.3.2 The AM-RoM in the context of the AM-IV

The composition of the Regulation-Oriented Model for Asset Management (AM-RoM) categorized in the context of AM-IV (Figure 4) in the 'AM Problem-solving Managerial Models' dimension, encompasses other dimensions and elements of AM as shown in Table 6.

Table 6 - AM-RoM in the context of AM-IV

| LAYER | DIMENSION | ELEMENT |
|---|---|---|
| External | Sector of the Economy | Energy |
| Middle | Business Strategy | Regulation<br>Risk Management |
| | AM Related-Standards | ISO31000 |
| Internal | AM Standards | ISO55001 |
| | AM Problem-solving Managerial Models | Regulation-Oriented Model for Asset Management Model (AM-RoM) |

Source: The author (2021)

The elements Regulation and Risk management of the 'Business Strategy' dimension, in the middle layer, used by the AM-RoM, are justified for the same reasons from the first Model. The main difference is about the Regulation, for which the experts had all the necessary regulatory information and, thus, were able to make a more in-depth analysis.

In the same way that the 'AM: Where to Start' Model connects with the ISO55001 and ISO31000 elements from the 'AM Standards dimension' and 'AM Related-Standards' dimension, respectively, so does the AM-RoM. The AM-RoM uses an adapted version of the common and complementary requirements of the two standards that resulted from the previous model.

### 2.3.3 The AMBP Model in the context of the AM-IV

In the context of the AM-IV (Figure 4), similarly to the previous two models, the AMBP Model is also categorized in the 'AM Problem-Solution Models' dimension. It relates to other dimensions and elements of AM, as shown in Table 7.

The elements Business Performance (KPIs), of the 'Business' dimension in the middle layer of AM-IV, and AM Performance assessment (APIs), of the assessment dimension in the internal layer of AM-IV, belong to the problem definition that the AMBP Model was developed to solve. The first, for being itself the main issue in the analysis of the relationship between AM and business; the second, for being a fundamental interface between AM and business.

Table 7 - AMBP Model in the context of AM-IV

| LAYER | DIMENSION | ELEMENT |
|---|---|---|
| External | Sector of the Economy | Transport; Health; Energy; Mining, Agribusiness; Local Council |
| Middle | Business | Business Performance (KPIs) |
| Internal | AM Frameworks & Models | GFMAM Framework 39 subjects |
| | AM assessment | AM Performance assessment (APIs) |
| | AM Problem-solving Managerial Models | Asset Management and Business Performance Relationship Model (AMBP Model) |

Source: The author (2021)

As for the elements Transport, Health, Energy, Mining, Agribusiness, and Local Council, the model was developed using case studies in AM, from asset-intensive companies in these sectors, which demand high availability and reliability from the companies' assets.

The AMBP Model uses, as the basis for its structure and methodology, the 39 AM subjects of the GFMAM Framework (GFMAM, 2014), which belongs to the 'AM Frameworks & Models' dimension of the AM-IV internal layer.

Given this theoretical background in the context of an integrated view of AM, the next chapters present the development and application of the conceptual models, followed by a discussion of the results and a brief final consideration. Chapters 3 and 4 present conceptual models for an AM managerial problem of an applied nature, supported by a decision-making process. Chapter 5 presents a conceptual model for an AM managerial problem of a theoretical nature. All three conceptual models were developed to meet some of the needs of asset-intensive companies.

# 3 ASSET MANAGEMENT: WHERE TO START MODEL

This chapter is based on the paper by LIMA, de LORENA and COSTA (2018). The AM Where to Start model was created in response to the aims outlined in the secondary objectives of the thesis: ‘To explore the prioritization problem with the support of a conceptual model, based on a general understanding of the Sector Regulatory Framework’ and ‘To test the conceptual model for its feasibility in an asset-intensive organisation’. Jointly with the Regulation-Oriented Model for Asset Management (AM-RoM) (Chapter 4), it answers the first research question ‘How to assist an asset-intensive organisation in implementing Asset Management (AM) and Risk Management (RM) whilst promoting the organisation conformance with the Sector Regulation?’.

## 3.1 CONTEXTUALISATION

Electric power industries have been growing fast in the last decades, and asset management (AM) is a challenging issue for them (KHALIQ; MAHMOOD; DAS, 2015). As they pursue important assets for the generation, transmission, and distribution of energy, it is crucial to regard asset management strategically, in order to become more efficient and sustainable.

In Brazil, the electricity sector is regulated and supervised by the *Agência Nacional de Energia Elétrica* – ANEEL (National Electric Power Agency), an autarchy linked to the Ministry of Mines and Energy under a special regime, with the mission to provide favourable conditions to develop the power market by balancing interests between agents and benefits for society (ANEEL, 2018a).

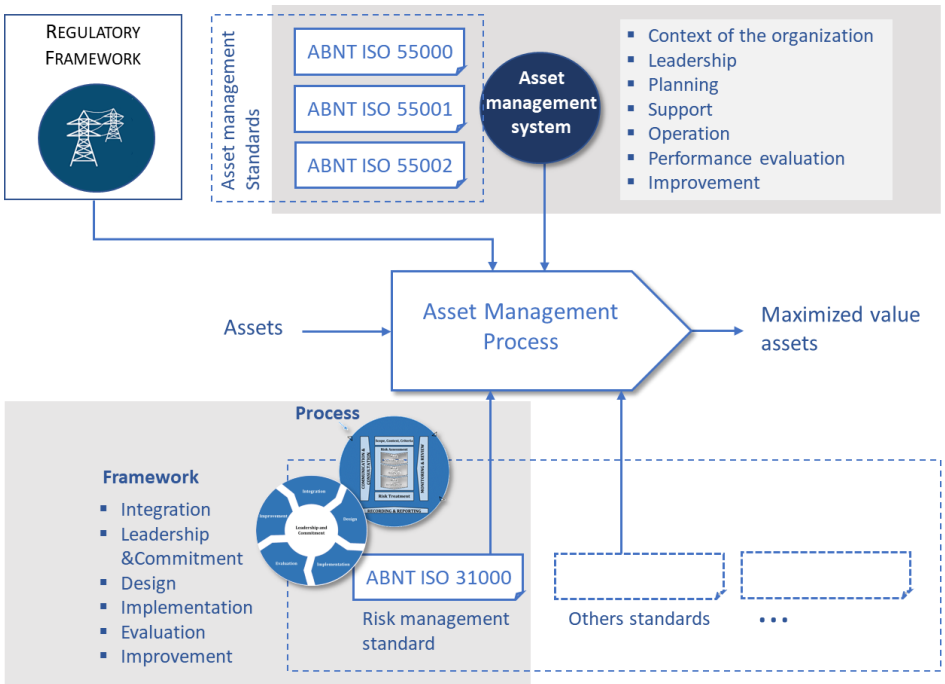
In the Power Transmission Sector, ANEEL is responsible for carrying out the activities of regulation, supervision, and resolution of issues, related to the access of users to the transmission system, as well as to the equipment and transmission facilities, the criteria for operation, operating capacity, minimum maintenance requirements, and the quality of service provision; Also, it is responsible for carrying out activities to deal with regulatory issues related to the Grid Procedures and to monitor the regulation (ANEEL, 2018b).

Efficiency and sustainability are two indispensable conditions to make organisations more valuable. Consolidated management models are a powerful tool that, if properly tailored to a given context, increases the organisation’s chances to become more efficient and sustainable, and therefore more structured to achieve strategic objectives.

According to Birkinshaw and Goddard (2009), some companies have discovered that a distinctive management model can itself be a key driver of competitiveness. Some of these consolidated management models are established by means of internationally recognized standards from the most diverse areas of knowledge, such as: Quality Management (ISO 9001:2015) (ISO, 2015a), Environmental Management (ISO 14001:2015) (ISO, 2015b), Risk Management (ISO Risk Guide and ISO 31000:2018) (ISO, 2009; ISO, 2018), Asset Management (ISO 5500X: 2014 and ISO 55010: 2019) (ISO, 2014a; ISO, 2014b; ISO, 2014c; ISO, 2019), among others. These Standards are usually about "what to do", and not about "how to do". Although some of them do not demand that organisations fulfil their requirements, they have been increasingly required by stakeholders. Nevertheless, organisations are obligated to comply with specific regulations of the sector in which they perform.

The Asset Management System (AMS), as detailed by ISO (2014b), is a managerial model that supports the asset management process, aiming to maximize the value of the organisation's assets. As the asset management process is susceptible to uncertainties, risk management is of fundamental importance. Figure 9 shows the main elements that support the AM process, for the purpose of this study.

Figure 9 - AM Process supported by ISO 55000:2014 and ISO 31000: 2018




Source: Lima, de Lorena and Costa (2018)

The AM process includes the entire asset life cycle (ALC) from the prospection, through acquisition, project, construction, operation and maintenance, to immobilization/ demobilization and disposal, under the aegis of strong and mandatory regulation. Managing assets is, by its nature, an inherently complex process since it involves functionalities of various areas of the organisation, specialized knowledge, and different levels of commitments, as well as it involves intensive information flow.

Many organisations recognize the importance of having their AM process implemented to ensure the value maximization of their assets, minimizing risks and being compliant with the regulation. However, some managers do not know how or have difficulty in implementing it, mainly due to the inherent complexities and critical nature of asset management decisions (IAM, 2015) and the fact that such decisions usually involve a significant amount of capital.

Structuring the AM process properly is essential to prioritize investments and concentrate efforts on the most critical assets. This allows the organisation to focus on the benefits that will bring the greatest gains, such as: improved financial performance, informed asset investment decisions, managed risk, improved services and outputs, demonstrated social responsibility, demonstrated compliance, enhanced reputation, improved organisational sustainability, and improved efficiency and effectiveness (ISO, 2014a).

Facing the need to survive in such complex situations, organisations are challenged by a seemingly simple but vague question, namely "Where to start?". This question is exactly what became important from a specific need of a large company in the Brazilian Energy Transmission Sector.

To answer the question outlined above, the AM: Where to Start Model was developed to guide the Brazilian company in implementing the asset and risk management in line with the sector’s regulation. It includes the joint analysis of ISO 31000:2018 (guidelines to risk management) (ISO, 2018), and ISO 55001:2014 (asset management) (ISO, 2014b). The model and its application in the Brazilian Company is described next, followed by the results and the final considerations of this study.

## 3.2 MODEL STRUCTURE

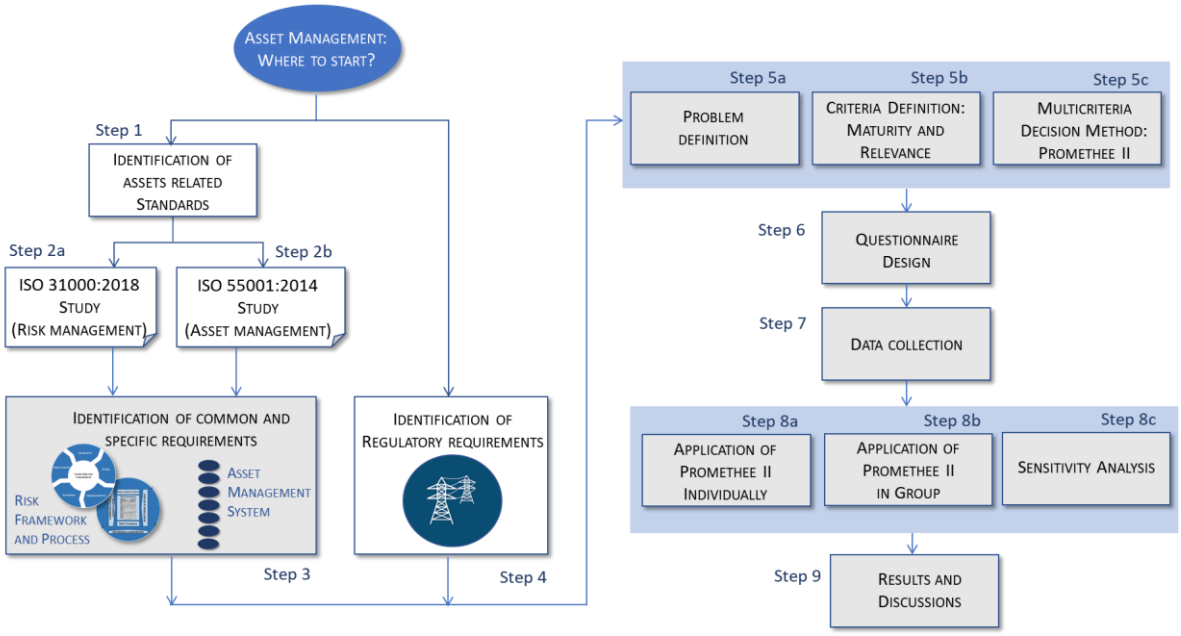
Following the guidelines of international standards is a fundamental move towards a successful asset management implementation, which means that numerous requirements need to be met. Due to human, financial, material, and other constraints, organisations need to make decisions about which requirements to implement with priority. In face of the complexity of the

problem, prioritization based on a single point of view becomes inadequate, hence the need to consider the knowledge of more than one expert. They are the ones who better know the asset management process and the regulatory aspects to which the organisation is obligated to adhere, and therefore the most appropriate professionals to sponsor decision-making on this issue.

Experts involved in the same scenario have similar objectives, have different perceptions about the same phenomenon and, through the analysis of available or deductible information, understand and experience the system and its environment (de ALMEIDA et al, 2012). In this study, ‘perception’ or ‘knowledge’ of the experts is their belief, based on their experience, about the ISO requirements or equivalent practices in the organisation, as well as the contribution of the ISO requirements to the organisation's compliance with the Sector Regulation. In the case of this study, a general understanding, and not an in-depth analysis of each of the requirements of the sector regulatory framework, is considered.

The Model has 9 steps drawn by the question 'Where to start?’. In other words, how is it possible for the organization to implement the AM process with a focus on the Electric Power Transmission Sector Regulation? Figure 10 presents the Model Structure.

Figure 10 - Model Structure




Source: Lima, de Lorena and Costa (2018)

Steps 1 to 3 propose to analyse the standards, regarding asset management and risk management, do not depend on the organization. The results do not vary with the application of the Model. The remaining steps depend on the organisation in which the Model is applied.

In Step 1, the identification of asset management related standards is realised. Among them, two are of extreme importance and are individually analysed in detail, in Step 2: ISO 55001:2014 and ISO 31000:2018. They describe the essence of asset management and risk management issues, respectively.

Other Standards identified in Step 1 are concerned to specific subjects that belong to relevant areas in asset management, such as the ones related to lifecycle cost, project management, quality management, and terotechnology. All these standards together, although not being part of this study, ensure the consistent delivery of an asset management process.

In Step 2 both ISO 31000:2018 and ISO 55001:2014 standards are analysed individually.

In Step 3, a comparison of both standards is performed, aiming at the identification of common or complementary requirements. The two management models complement each other when they are instantiated to the same process, in this case, the AM process. The result of Step 3 is a list of the ISO requirements, which are the alternatives to be evaluated by the experts.

In Step 4, the regulatory scope that will be referenced in the evaluation in Step 7 is defined.

Step 5 is composed of the problem's type, criteria definition, and the election of a multicriteria decision method.

Step 6 describes how the questionnaire for data collection is designed.

Step 7 represents the data collection, which encompasses the assessment of the alternatives for each criterion (intra-criteria evaluation), by each of the *j* experts, as well as the establishment, by a decision-maker, of his/her preferences on the criteria (inter-criteria evaluation). This is done by assigning a value to each criterion ($w_m$), which correspond to the importance he/she attributes to them. The result is *j* decision matrix, that are the input for Step 8, shown in Table 8.

Table 8 - Decision Matrix

| ALTERNATIVES (ISO REQUIREMENTS) | CRITERIA | | | |
|---|---|---|---|---|
| | $C_1$ | $C_2$ | … | $C_m$ |
| | $w_1$ | $w_2$ | … | $w_m$ |
| $ISO_1$ | $V_1(ISO_1)$ | $V_2(ISO_1)$ | … | $V_m(ISO_1)$ |
| $ISO_2$ | $V_2(ISO_2)$ | $V_2(ISO_2)$ | … | $V_m(ISO_2)$ |
| ... | … | … | … | … |
| ... | … | … | … | … |
| $ISO_n$ | $V_1(ISO_n)$ | $V_2(ISO_n)$ | … | $V_m(ISO_n)$ |

Source: Adapted from de Almeida (2012)

In Step 8a, PROMETHEE II (Preference Ranking Organisation Method for Enrichment of Evaluations) is firstly applied individually for each of *j* decision matrix. The result is a set of *j* lists of ISO requirements prioritized, individually, according to the individual preferences of the decision-maker who performed the inter-criteria assessment for that decision matrix.

In Step 8b, PROMETHEE II is applied considering each decision-maker as a criterion of equal importance *p* or different importance $p_1, p_2, \ldots, p_m$ depending on the context. The result is one unique list of ISO requirements prioritized according to the aggregation of the *j* decision-makers' preferences, in the 'output level aggregation'[3].

When a process involves an opinion or judgment by two or more decision-makers or experts, an analytical aggregation procedure for decision-makers' preferences or experts' knowledge is important to support decisions. It ensures the rationality of those who are part of the process, and the achievement of more efficient results for the parties involved (de ALMEIDA et al, 2012). There is a difference between preference aggregation and knowledge aggregation. An analytical procedure for the former aims to obtain the preference structures of decision-makers who do not always seek the same results, whereas an analytical procedure for aggregating knowledge of experts involves the treatment of different perceptions concerning the same phenomenon, as they have similar purposes. Furthermore, de Almeida et al (2012) state a distinction between decision-makers and experts' roles. The former has the power to make decisions, while the latter understands the system and its environment.

Step 8c submits the data to a sensitivity analysis to check the robustness of the results, and Step 9 performs the result analysis.

## 3.3 MODEL APPLICATION

### 3.3.1 Asset Management versus Risk Management

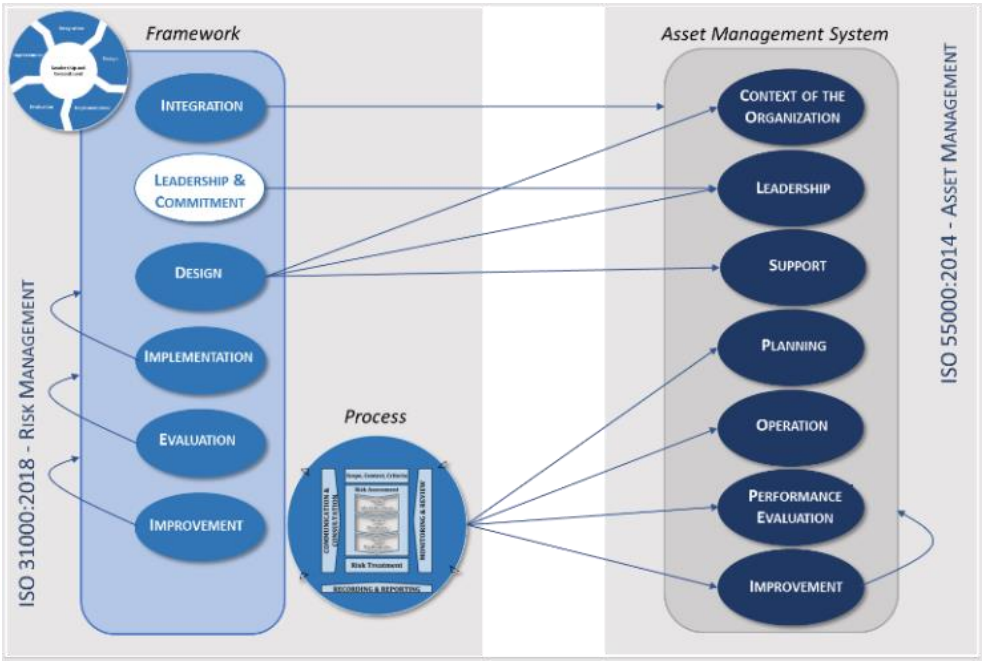
After the identification (Step 1) and individual analysis of the standards ISO 55001:2014 (ISO, 2014b) and ISO 31000:2018 (ISO, 2018) (Step 2), an analysis of the equivalences, between the Asset Management System (AMS) and the risk management framework and process, detailed in the two standards, respectively, was performed.

[3] When aggregating preferences, the literature recognizes two main approaches: input level aggregation and **output level aggregation**. Alternatives, criteria and weights are established previously in a group discussion for input aggregation. Whereas in the latter, only the alternatives are defined in consensus, as individual results are constructed by each member and then aggregated into a final collective group result that considers each decision-maker as the same or different criterion. The criteria weights refer to the importance of the criteria established by the decision-maker in the group (SILVA; MORAIS; de ALMEIDA, 2010).

Both AMS and RM framework and process are management models. Although the term ‘management model’ is utilized in many contexts with different meanings, it is understood as “the choices made by a company’s top executives regarding how they define objectives, motivate effort, coordinate activities and allocate resources; in other words, how they define the work of management” (BIRKINSHAW; GODDARD, 2009). Not all organisations have structured management models, but all of them have equivalent practices for the management of their assets.

In Step 3, it was observed, as depicted in Figure 11, that all the dimensions extracted from ISO 55001:2014 (‘context of the organisation’, ‘leadership’, ‘support’, ‘planning’, ‘operation’, ‘performance evaluation’ and ‘improvement’) are related to the component ‘integration’ in ISO 31000:2018.

Figure 11 - ISO 31000:2018 framework and process versus ISO 55001: 2014 AM System




Source: Lima, de Lorena and Costa (2018).

In the same way, ‘leadership’ in ISO 55001:2014 relates to ‘leadership & commitment’ and ‘design’ in ISO 31000:2018, ‘support’ in ISO 55001:2014 also relates to ‘design’ in ISO 31000:2018. Furthermore, the dimensions ‘planning’, ‘operation’, ‘performance evaluation’ and ‘improvement’ in ISO 55001:2014 are completely related to the risk management process. Conversely, some requirements were identified to be specific for the implementation of the ISOs separately. For instance, ‘implementation’, ‘evaluation’, and ‘improvement’ in ISO 31000:2018

refer precisely to risk management framework, and ‘improvement’ in ISO 55001:2014 refers to the asset management as well as the asset management system itself.

All these relationships are detailed in Table 9, where RM, AM and AMS are the abbreviations for risk management, asset management and asset management system, respectively. Also, the 29 ISO requirements, that are the result of the analysis of the two standards (ISO 55001 and ISO 31000), are shown in Table 10.

### 3.3.2 Regulatory Framework

In Step 4 the regulatory scope for analysis is defined. Although in the model the assessment of the scope of the regulatory requirements on an individual detailed basis is not considered, it is important to make the context and the scope in question clear to the decision-makers. This knowledge is necessary because the AM&RM ISO requirements are assessed on their ability to contribute to the organization in meeting regulatory requirements.

### 3.3.3 Problem type, Criteria and Method

In Step 5, three definitions were performed: the problem type, the criteria and the multicriteria decision-making support method, as described herein.

#### 3.3.3.1 Problem Type

Large organizations have in their management function an inherent complexity aimed at the need for multifunctionality in decision making, specialized knowledge, different levels of commitments, and intensive information flow. In the organization where the model was developed, the managers recognized the benefits of a structured AM&RM process, as well as the importance of prioritizing investments and efforts on the most critical assets. As they are responsible for an asset-intensive organisation, they dealt with the obligation to be compliant with the regulation of the power transmission sector.

Regarding the problem type, because of the organisation's resource constraints, it was necessary to prioritize the requirements to establish the action plan for a future asset management process implementation focusing on the regulation. In this case, the intended result for the problem was associated with the Ordering Problem (P. $\gamma$)[4].

[4] According to Roy (1996) apud de Almeida (2012), there are four types of problems, depending on the intended result: Choice Problem (*P.* $\alpha$); Classification Problem (*P.* $\beta$); Ordering Problem (*P.* $\gamma$); Description problem (*P.* $\delta$). To this list, de Almeida (2012) also adds the Portfolio Problem.

Table 9 - Relationship between ISO 31000:2018 and ISO 55001:2014

| ISO 31000:2018 | ISO 55001:2014 |
|---|---|
| **Framework** *Integration:* RM is a dynamic and iterative process that is part of "the organizational purpose, governance, leadership and commitment, strategy, objectives and operations". Everyone must be responsible for RM. | Every AMS requirement is related to *integration* in ISO (2018) once the former cites the importance of RM in every step. |
| **Framework** *Leadership& commitment:* Top management and oversight bodies must be aligned to ensure that RM is integrated into all activities, and "should demonstrate leadership and commitment". | *Leadership:* "Top management shall demonstrate leadership and commitment with respect to the AMS", ensuring that the approach used for managing risks is aligned with the organisation's approach for AM. |
| **Framework** *Design:* Implies the examination and understanding of organisation external and internal context.<br>The organisation must demonstrate the commitment to RM through a policy, considering the possibility to link it to other existing policies.<br>Organisational roles, authorities, responsibility and accountabilities must be assigned and communicated at all levels. Appropriate resources should be allocated, and a communication and consultation approach should be established | *Context of the organisation:* The organisation must determine its external and internal issues that affect its ability to achieve the outcome(s).<br>*Leadership:* An AM policy should be established with consistency with other relevant organisational policies.<br>*Support:* Organisations must communicate AM objectives, associating risks and opportunities. Information requirements must also be determined to support assets, AM, and AMS, considering identified risks. |
| **Process** *Risk Assessment:* Includes the process of identifying, analysing and evaluating risks. The determination of a process's risks and opportunities and their level of intensity are conceived.<br>*Risk Treatment:* Assessed risks and opportunities shall be treated by selecting actions that may control them by avoiding, removing, changing likelihood, among others. These actions must be documented in a risk treatment plan. | *Planning:* When planning AMS, the organisation shall determine the risks and opportunities that need to be foretold or reduce undesired effects. The organisation must determine and document actions to address risks and opportunities, considering how they may change with the passing of time. In addition, the risks found in AM must be considered in the organisation's contingency planning. |
| **Process** *Risk Assessment:* When evaluating risks and opportunities, the organisation can support decisions that may lead to changes, considering the context and consequences to stakeholders.<br>*Risk Treatment, Monitoring and Review:* "The purpose of risk treatment plans is to specify how the chosen treatment options will be implemented" and, consequently monitored. Monitoring and review aim to "assure and improve the quality and the effectiveness of process design, implementation and outcomes". | *Operation:* Risks derived from any planned change (permanent or temporary) that may impact achieving the AM objectives, must be assessed before the implementation of the change. Besides, when outsourcing any activities that have the same impact, the associated risks must be equally assessed.<br>"The organization shall plan, implement and control the processes by treating and monitoring risks". |
| **Process** *Recording and Reporting:* "The RM process and its outcomes should be documented and reported through appropriate mechanisms", aiming to communicate them, provide information for decision-making, improve RM activities, and support the interaction with stakeholders. | *Performance evaluation:* "The organization shall evaluate and report on the effectiveness of the processes for managing risks and opportunities". Management review may consider changes in the risks and opportunities' profiles.<br>*Improvement:* Information must be documented as evidence of non-conformities or incidents, also considering the actions that are taken and results. |

Source of basic data: ISO (2018) and ISO (2014b)

Table 10 - ISO 55001 and ISO 31000 requirements consolidation

| ISO DIMENSIONS | CODE | REQUIREMENTS CONSOLIDATION (ISO 55001 AND ISO 31000) |
|---|---|---|
| ORGANISATION CONTEXT | C1 | Understanding of the organisation and its internal and external contexts. |
| | C2 | Establishment of criteria for AM decision making in considering the needs and expectations of stakeholders. |
| | C3 | Determining the scope of the AM system |
| | C4 | Establish, implement, maintain, and continually improve an AM system. |
| LEADERSHIP | L1 | Leadership and commitment of senior management regarding risk management integrated to the AM process, as well as the establishment of policies, resource allocation and multi-functional collaboration. |
| | L2 | Existence of an AM policy and a RM policy, properly documented, communicated, and available to interested parties, both converging in objectives. |
| | L3 | Responsibility, authority, and competence, attributed and communicated by the Organisation, both for AM and for the management of its risks. |
| PLANNING | P1 | Incorporation of RM practices and processes into AM practices and processes, making them an integral part of the AMS. |
| | P2 | Contemplation of the requirements of relevant stakeholders and other financial, technical, legal, regulatory and organisational requirements in the objectives of AM. |
| | P3 | Establishment of the AM Plan in line with the AM policy, in accordance with the RM plan, including methods and criteria for decision making; processes and methods for managing the asset throughout its life cycle. |
| SUPPORT | S1 | Provision of resources for the AM System, AM and RM, including people with skills and competences, methods and tools, documented procedures, information systems and training programs. |
| | S2 | Determination of the requirements for the competence needed by professionals who perform the work that affect the performance of assets, AM and AM System. |
| | S3 | Professionals fully aware of their role in the Asset Management process |
| | S4 | Determination of internal and external relevant communication needs to assets, AM System and AM and their risks. |
| | S5 | 'Roles and responsibilities, the significance of risks, consistency and trace-ability of financial and technical data' clearly defined, in order to comply with legal and regulatory requirements. |
| | S6 | Documented and controlled internal and external information to meet legal and regulatory requirements |
| | S7 | Control of the documented information required by the AM System, of internal and external origin, ensuring its availability and suitability for use, and adequate protection. |
| OPERATION | O1 | Planning, implementation, and control of the processes necessary to meet the AM objectives in order to ensure that the RM process is an integral part of the AM process. |
| | O2 | Early assessment of the risks associated with any planned change, which may have an impact on the achievement of the AM objectives. Critical analysis and continuous monitoring of the risk treatment progress. |
| | O3 | Risk assessment of outsourced activities and processes that may impact the AM objectives, including accountability and authority; the processes and scope for sharing knowledge and information; and the performance of outsourced activities. |

Table 10 – ISO 55001 and ISO 31000 requirements consolidation (Continuation)

| ISO DIMENSIONS | CODE | REQUIREMENTS CONSOLIDATION (ISO 55000 AND ISO 31000) |
|---|---|---|
| PERFORMANCE EVALUATION | E1 | Determination of when and what should be monitored and which methods are used to measure, analyse, evaluate, document and report the results of the performance of the assets, AM and RM and the effectiveness of AM System. |
| | E2 | Conducting internal audits at planned intervals aiming at: how much the AM System is in compliance with the requirements of ISO55000. |
| | E3 | Critical analysis, at planned intervals, of the AM performance; opportunities for continuous improvement; and changes in the risks and opportunities profile. |
| IMPROVEMENT | I1 | Carrying out actions to deal with the consequences, when there is a non-conformity or incident with the assets, AM or AM System, including: critical analysis of non-compliance and the effectiveness of corrective actions taken. |
| | I2 | Establishing processes to proactively identify potential failures in AP and assessing the need for preventive actions. |
| | I3 | Continuous improvement of the relevance, adequacy and effectiveness of AM and AM System, as well as the integration of the RM process with the AM process. |
| RISK STRUCTURE | F1 | Periodic assessment of the effectiveness of the RM structure, considering its objectives, the implementation of plans, indicators and expected behaviours. |
| | F2 | Implementation of the RM structure to ensure that the RM process is an integral part of the AM process. |
| | F3 | Continuous improvement of the RM structure as well as the integration of the RM process with the AM process. |

Source of basic data: ISO (2018) and ISO (2014b)

#### 3.3.3.2 Criteria

According to the objective of the organisation, which is to implement AM and RM while contributing to the compliance with the regulatory framework of the Power Transmission Sector, two criteria were determined: ‘maturity’ and ‘relevance’.

Maturity criterion comprising the level of implementation of the requirement in the organisation, according to ISO (2014b) and ISO (2018) or the equivalent practices in the organisation. A lower maturity means that the requirement under analysis is a little or not implemented in the organisation, thus, there would be opportunities for the asset management process improvement. A higher maturity means that the organisation has the ISO requirement, or the equivalent practices. implemented or in a good degree of implementation, perceived by the experts.

Relevance criterion representing the extent to which the ISO requirement, if implemented, contributes to the organisation being able to meet the specific regulation

requirements of the sector. That is, a greater relevance means that the requirement under analysis is relevant to the organisation to be in compliance with the Sector Regulation and, consequently, would increase the possibility of the organisation receiving a fair reward. On the other hand, a lower relevance means that the implementation of the ISO requirement will have a low or no contribution to the organisation in terms of in compliance with the regulatory framework.

The criteria, maturity and relevance, were chosen from the objectives of the organisation, and according to the properties of measurability, operability, and comprehensibility, as suggested by Keeney (1992).

#### 3.3.3.3 Multicriteria decision-making support method

The PROMETHEE II Multicriteria Decision Method was chosen mainly because (a) it addresses an ordering problem; (b) it is a non-compensatory method, which is compatible with the characteristics of the problem; and (c) it is an outranking method, which, according to Sabei, Erkoyuncu and Roy (2015), does not "eliminate any alternative in pairwise comparison instead it puts the alternatives in an order according to criteria and decision-maker preference", thus it allows the choice of the best alternative from the outranked set.

Among other multicriteria methods, the family PROMETHEE has proved to be considerably present in empirical studies in recent years, as many papers have been written with great success (SABEI; ERKOYUNCU; ROY, 2015). This method stands out for involving concepts that are easily understood by decision-makers as they can build criteria that represent their notion of preference; besides it fixes a maximum number of two parameters (preference and indifference) with real economical interpretation (BRANS; VINCKE, 1985).

According to Brans, Vincke and Mareschal (1986), PROMETHEE has the advantage of being clear, simple and stable. PROMETHEE includes two main phases: the construction of an outranking relation, and the exploitation of this relation. During the first phase, a preference function must be established for each criterion, representing the decision-makers' preference for action '*a*' over an action '*b*'. Hence, the intensity of the preference rises with the difference between the performance of the alternatives.

$$F(a,b) = f[g(a) - g(b)] \quad (1)$$

The values are defined between *0* and *1*. There are six types of functions that could cover most of the cases: usual criterion, quasi-criterion, criterion with linear preference, level-criterion, criterion with linear preference and indifference area, and the gaussian criteria. In case the problem has more than one criterion, it is possible to mix the functions (BRANS; VINCKE,

1985). In the second phase, the preference index must be defined for each pair of alternatives using the functions and the weights of the criteria that represent their relative importance. In other words, the preference index "is defined as a weighted average of preferences of the individual criteria" (SILVA; MORAIS; de ALMEIDA, 2010).

$$\pi(a,b) = \frac{\sum_{i=1}^{k} \pi i Fi(a,b)}{\sum_{i=1}^{k} \pi i} \quad (2)$$

The exploitation of the outranking relation consists of defining the outgoing flow, $\phi^{+}(a)$, and the incoming flow, $\phi^{-}(a)$. The former implies the intensity of preference of *a* over the other alternatives, whereas the second is the opposite, which means the intensity of all the alternatives over *a*.

$$\phi^{+}(a) = \sum_{x \in K} \pi(a,x) \quad (3)$$

$$\phi^{-}(a) = \sum_{x \in K} \pi(x,a) \quad (4)$$

where $K$ is the set of possible alternatives.

In the family PROMETHEE, Brans and Vincke (1985) explain that PROMETHEE I represents a partial relation and PROMETHEE II the total pre-order (complete ranking) by calculating the net flow.

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \quad (5)$$

Consequently, *a* outranks *b* or *a* is indifferent to *b*, respectively, if:

$$\phi(a) > \phi(b) \quad (6)$$

$$\phi(a) = \phi(b) \quad (7)$$

Further details on PROMETHEE II can be found in Brans and Vincke (1985) and Keyser and Peeters (1994).

For this application, the preference usual function was applied for both criteria as the data were collected based on a 5-point Likert scale, becoming needless the use of preference and indifference thresholds.

### 3.3.4 Questionnaire design and data collection

In Step 6, the questionnaire was designed with 29 requirements originated from the joint analysis of ISO 31000:2018 and ISO 55001:2014 from Step 3 (Table 10). A 5-point Likert scale was selected to be used, as it has a good performance considering reliability, validity, discriminating power and respondent preferences (PRESTON; COLMAN, 2000).

The evaluation for criterion 'maturity', expressing the experts' knowledge in the asset management process, varies from 'not implemented' to 'completely implemented'. Similarly, the evaluation for the criterion 'relevance', expressing the experts' knowledge in how the

implementation of an AM and RM requirement is relevant to the organisation compliance with the regulation of the sector, includes ‘totally disagree’ to ‘totally agree’. The questionnaire was applied to four homogeneous experts[5] in knowledge on the subject under study, as shown in Table 11. In Step 7, the experts assessed each of the 29 alternatives for each criterion.

Table 11 - Characteristics of the Experts

| KNOWLEDGE AREAS | EXPERTS | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **4** |
| Asset Operation and Maintenance | X | | X | |
| Asset Management Process | X | X | X | X |
| Sector’s Regulation | X | X | X | X |

Source: Lima, de Lorena and Costa (2018)

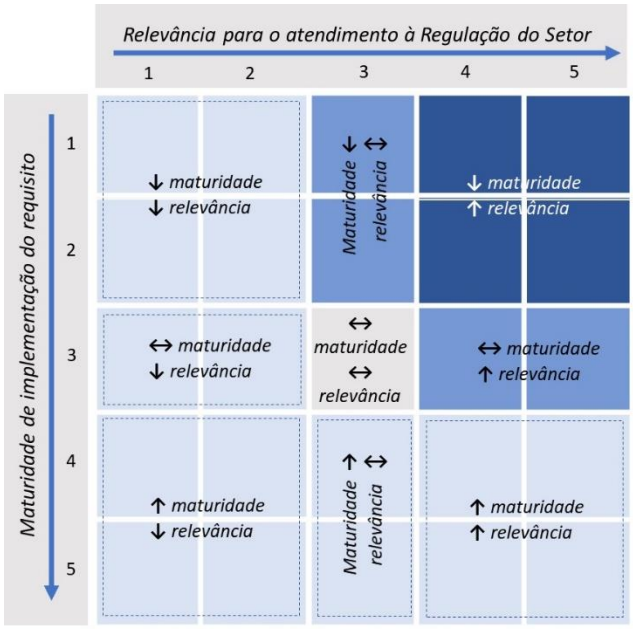
Also, in Step 7 the decision-makers were asked to establish weights to both criteria, expressing their preferences regarding the importance for the analysis of ISO requirements. Particularly, for this application, the experts acted in the role of decision-makers in making their preferences explicit. The result of this step was four individual decision matrices.

Figure 12 shows the evaluation quadrants of the relevance and maturity criteria. Figure 13 shows the evaluations performed by each of the four experts.

It should be noted that most of the evaluations are concentrated in the quadrants where the organisation has a low maturity in implementation of the requirement and there is a high relevance for meeting the sector's regulation. There is a concentration of evaluations in the most critical quadrants, although it is not possible to identify which are the 29 requirements in each of them. This visual result reinforces the need to establish a prioritization, which is achieved with the application of the Multi-Criteria Decision Method (MCDM).

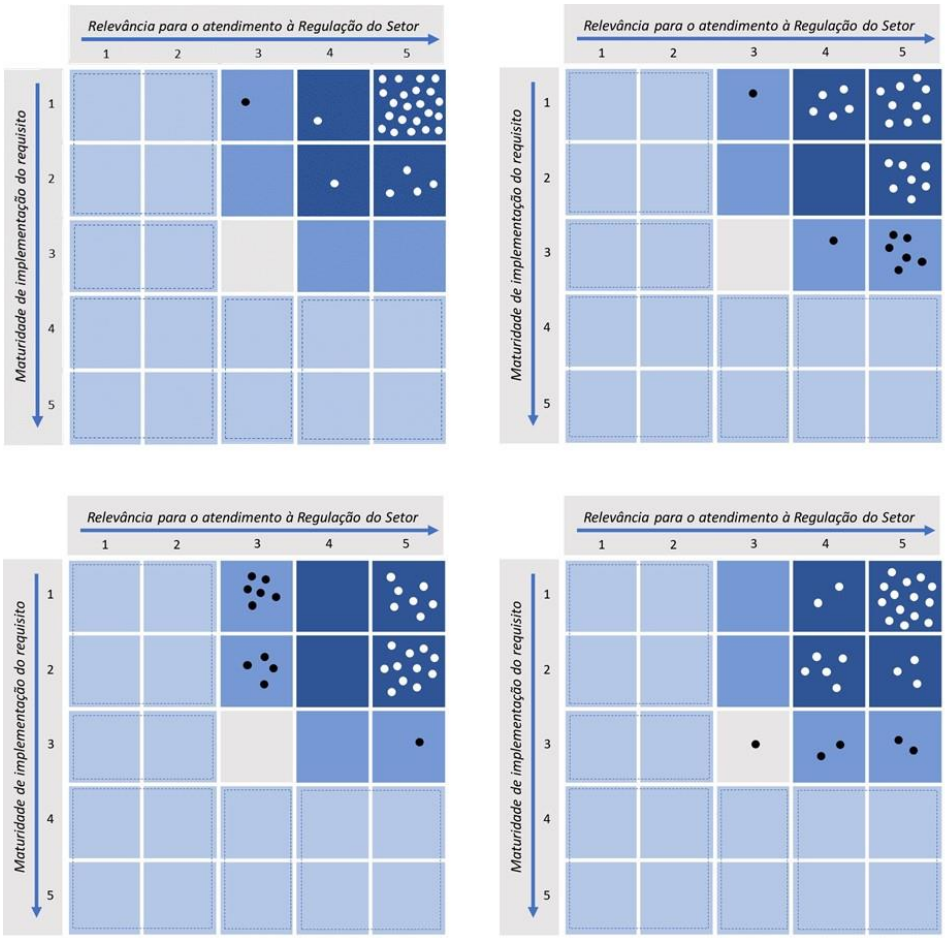
[5] All of them were senior professionals, with many years working in the organization in areas related to asset management or regulation.

Figure 12 - Criteria evaluation quadrants




Source: The author (2021)

Figure 13 - Experts' evaluations




Source: The author (2021)

### 3.3.5 PROMETHEE II: individual and group application

In Step 8a, performing PROMETHEE II individually, first, each of the 29 ISO requirement was considered as an alternative, evaluated by the *j* experts under both criteria, based on their knowledge; and second, the *j* decision-makers expressed their preferences, as they defined individually the weights of the criteria ($w_{j1}$, $w_{j2}$). In Step 8b, Performing PROMETHEE II in a group, the decision-makers (DM) were considered as criteria ($DM_{1,2,3,4}$) of the same importance *p*, to aggregate the individual rankings into a global one. Figure 14 summarizes the decision-makers' preferences aggregation process.

The results are shown in the PROMETHEE GAIA plane (BRANS; de SMET, 2016) in Figure 15 and in Table 12. The former aids with the visual understanding of the requirements' performance of the group preference aggregation. The ISO requirements are presented as squares, the vectors are the criteria, and the red axis ($\pi$) represents their weighing. The solution neatness achieved 100%, indicating that the information obtained in GAIA plane is reliable. The requirement L1 (Leadership 1), which is the 'leadership and commitment of senior management regarding risk management integrated to the AM process, as well as the establishment of policies, resource allocation and multi-functional collaboration' is oriented towards the direction of $\pi$-axis, which is the best-ranked option also viewed in Table 12. On the other hand, requirement S1 (Support 1), which is the 'provision of resources for the AM System, AM and RM, including people with skills and competences, methods and tools, documented procedures, information systems and training programs', in the opposite direction, is the worst ranked requirement. It is relevant to highlight that requirement L1 is fundamental for the success of the AM implementation, since the leadership is responsible for engaging the team so that the AM objectives are aligned with the organization's goals.

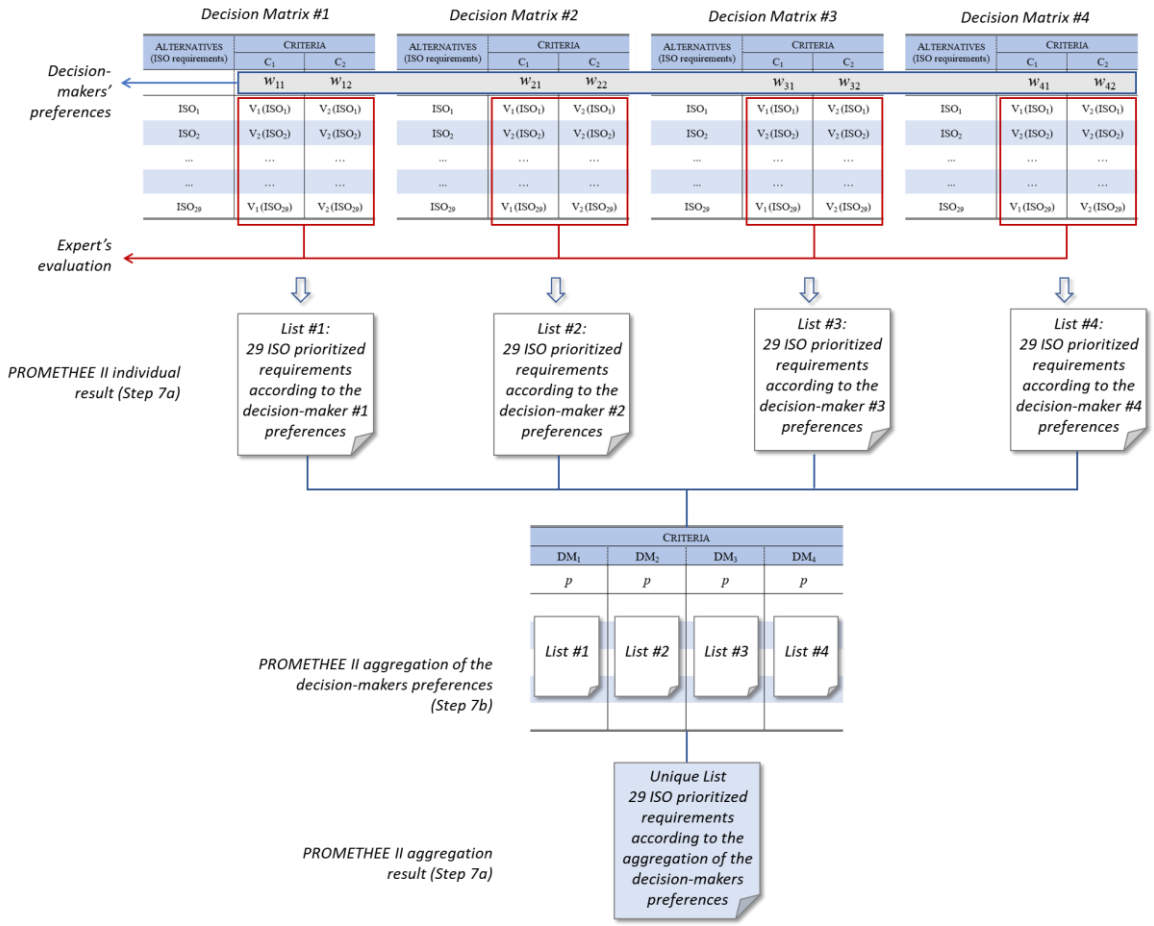
Considering the context of the studied organisation, an analysis of the first ten positions in Table 12 shows two dimensions, Support and Operation, of which in each dimension three requirements were prioritized. The first 5 prioritized ISO requirements were:

1) Leadership 1: Leadership and commitment of senior management regarding risk management integrated to the AM process, as well as the establishment of policies, resource allocation and multi-functional collaboration.

2) Support 3: Professionals fully aware of their role in the Asset Management process.

3) Operation 2: Early assessment of the risks associated with any planned change, which may have an impact on the achievement of the AM objectives. Critical analysis and continuous monitoring of the risk treatment progress.

Figure 14 - Decision-makers' preferences aggregation process




Source: The author (2021)

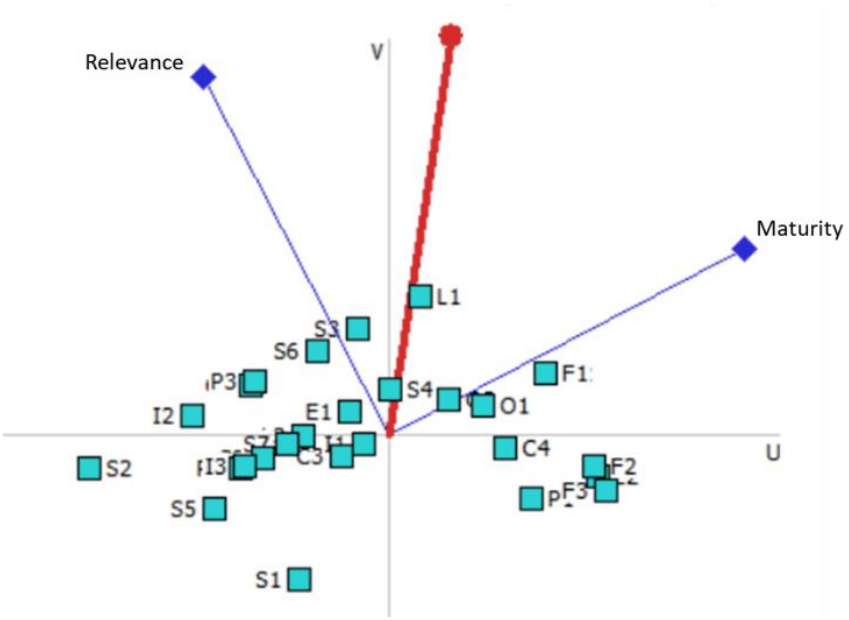
4) Framework 1: Periodic assessment of the effectiveness of the RM structure, considering its objectives, the implementation of plans, indicators and expected behaviours.

5) Support 6: Documented and controlled internal and external information to meet legal and regulatory requirements.

### 3.3.6 PROMETHEE II: Sensitivity Analysis

The sensitivity analysis is performed based on the variation of the input parameters, for example, the preference of decision-makers, which reflect the criteria weights. More robust forms than the one used here include the variation of these weights up and down. In the individual analysis by the decision-makers, the results indicated diversity among their preferences when judging the criteria's importance. In the sensitivity analysis, a simplified form was adopted in order to equalize the weights attributed by the decision-makers for both maturity and relevance criteria. The result of the sensitivity analysis showed a collective ranking with no significant differences in the order of the requirements.

Figure 15 - The PROMETHEE Gaia plane analysis for the group of experts




Source of basic data: Visual PROMETHEE

Table 12 - PROMETHEE II Requirements Final Ranking

| | Requirement | ϕ+ | ϕ− | ϕ | | Requirement | ϕ+ | ϕ− | ϕ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Leadership1 | 0,3045 | 0,0536 | 0,2509 | 16 | Leadership2 | 0,2509 | 0,2687 | -0,0179 |
| 2 | Support3 | 0,267 | 0,0911 | 0,1759 | 17 | Improvement2 | 0,1973 | 0,2196 | -0,0223 |
| 3 | Operation2 | 0,267 | 0,1187 | 0,1482 | 18 | Improvement1 | 0,217 | 0,2411 | -0,0241 |
| 4 | Framework1 | 0,267 | 0,1187 | 0,1482 | 19 | Leadership3 | 0,2045 | 0,2321 | -0,0277 |
| 5 | Support6 | 0,242 | 0,1161 | 0,1259 | 20 | Framework3 | 0,2295 | 0,2687 | -0,0393 |
| 6 | Support4 | 0,2348 | 0,1589 | 0,0759 | 21 | Support7 | 0,2027 | 0,25 | -0,0473 |
| 7 | Operation3 | 0,3009 | 0,225 | 0,0759 | 22 | Context3 | 0,2295 | 0,2821 | -0,0527 |
| 8 | Operation1 | 0,2295 | 0,1563 | 0,0732 | 23 | Planning1 | 0,2188 | 0,2955 | -0,0768 |
| 9 | Planning3 | 0,2348 | 0,1821 | 0,0527 | 24 | Context2 | 0,1991 | 0,2768 | -0,0777 |
| 10 | Context1 | 0,2241 | 0,1768 | 0,0473 | 25 | Improvement3 | 0,1777 | 0,275 | -0,0973 |
| 11 | Evaluation1 | 0,217 | 0,1911 | 0,0259 | 26 | Planning2 | 0,167 | 0,2696 | -0,1027 |
| 12 | Context4 | 0,2277 | 0,2232 | 0,0045 | 27 | Support2 | 0,1786 | 0,325 | -0,1464 |
| 13 | Evaluation2 | 0,2348 | 0,2366 | -0,0018 | 28 | Support5 | 0,1688 | 0,3518 | -0,1830 |
| 14 | Evaluation3 | 0,2348 | 0,2366 | -0,0018 | 29 | Support1 | 0,1045 | 0,3884 | -0,2839 |
| 15 | Framework2 | 0,2348 | 0,2366 | -0,0018 | | | | | |

Source: Lima, de Lorena and Costa (2018)

## 3.4 FINAL CONSIDERATIONS

The objective of this Model was to contribute to a real problem of a large Brazilian company, in order to answer the question: "Where to start?", that is, how should the organisation implement asset management while adequately attend to the Electric Power Transmission Regulation.

The AM: Where to Start Model was proposed to order the ISO requirements (from a joint analysis of ISO 55001:2014 and ISO 31000:2018), according to the aggregation of the decision-makers' preferences. Two criteria: maturity and relevance were evaluated based on the perception or knowledge perspective from the experts in Asset Management and Regulation. The result is an important input for the organisation to establish an action plan for a future asset management process implementation.

Although the Model was developed to solve a problem experienced in a Power Transmission Company in Brazil, it can be applied to companies from other sectors of the economy, considering their specific regulation.

For future studies, other standards related to asset management shall be considered. Furthermore, it is suggested an application that deepens the regulatory issue and aggregates strategic guidelines, such as the definition of what the organisation wants to achieve by means of AM, and the actor's roles and responsibilities in the problem-solution. Incorporating an aggregation of the expert's knowledge in decision-making modelling should allow better information about the alternatives and, consequently, promote a better decision. This is suggested for future work, as well.

The next chapter presents a conceptual model that incorporates these suggestions. Both chapters offer models which were built for the same strategic context, the Regulatory context, to support decisions. Although the models use different methods to prioritize the AM and Risk requirements with focus on regulation, the aim of the thesis is not to compare the results.

# 4 REGULATION-ORIENTED MODEL FOR ASSET MANAGEMENT

This chapter is extracted from the paper by LIMA and COSTA (2019). The Regulation-Oriented Model for Asset Management (AM-RoM) attend to the secondary objectives of the thesis: ‘To deepen understanding of the prioritization problem with the support of a conceptual model, based on strategic directions and on an in-depth analysis of the Sector Regulatory Framework’ and ‘To test the conceptual model for its feasibility in an asset-intensive organisation’. Jointly with AM Where to Start model (Chapter 3), it answers the first research question ‘How to assist an asset-intensive organisation in implementing Asset Management (AM) and Risk Management (RM) whilst promoting the organisation conformance with the Sector Regulation?’.

## 4.1 CONTEXTUALISATION

Organisations have a major challenge which is to ensure that products and services add value to stakeholders in their business. This becomes more critical in organisations that deal with a multi-asset system, defined by Petchrompo and Parlikad (2019) as “a system composed of multiple assets that share common characteristics or resources under the control of an organization”. In such systems, the organisations must manage an inherently complex process. This involves functionalities of diverse areas, specialized knowledge, and different levels of commitment. Besides this, they have to deal with a great amount of diverse and, at times, conflicting information. This complexity requires efficient asset management (AM), which is the essence of the Asset Management – AM discipline.

More critical than multi-asset system organisations are those subject to a specific regulation imposed by the granting public authority, which acts on various sectors of the economy as water, energy, telecommunications, aviation, among others. These organisations need to be very well managed to extract greater value from their assets while being sustainable and competitive and, simultaneously, having to be in compliance with a strong regulatory framework.

Regulatory practices are different in each country. However, the aim is usually to keep costs and revenues under control, while requiring service of high reliability and efficiency (CATRINU; NORDGÅRD, 2011). In this research, the concept of Regulation is the one defined in the analysis developed by Koop and Lodge (2017) as an “Intentional intervention in the activities of a target population, where the intervention is typically direct – involving binding

standard-setting, monitoring, and sanctioning – and exercised by public-sector actors on the economic activities of private-sector actors". The regulation comprises all the standards and rules that are established by the regulatory agencies.

The inherent condition of regulated organisations, coupled with the unpredictability of business environments, leads to a quite complex situation and requires better practices from companies to properly manage their assets. In this compound situation, not only Asset Management but also Risk Management – RM should be considered. As all activities involve risks at any level, proper decisions must be made by the organisations to manage these effects. In this perspective, asset and risk management practices are vitally important and are intensively being studied in various sectors of the economy for many types of assets (CATRINU; NORDGÅRD, 2011; ICA, 2015; MILINA et al., 2017; NEIJENS, 2017; SEPP NEVES et al., 2015; CHOO, 2015; DASHTI; YOUSEFI, 2013; MALETIČ et al. 2018; AVEN; RENN, 2018).

The AM process is complex in nature and the need to meet standards by organisations introduces even greater sophistication. Due to constraints, such as human, financial and material, among others, organisations need to decide which investments in AM&RM practices should be implemented to gain a better valuation of their assets and at the same time be compliant with regulation. Although, even with the expected capability of these two management models, whose integration promotes much greater synergy, a question emerges: 'What are the AM and RM priority requirements that must be implemented in the organisation to make it compliant with the sector´s regulation?'.

Considering that resources are restricted and a project to improve the AM process requires considerable effort and costs, it is important not only to identify among the AM and RM ISO requirements those that will bring better results in attending regulations, but also defining from which criteria they will be evaluated.

To implement and improve AM and RM, organisations rely on conceptual models. Examples of internationally known models are: The IAM Conceptual Model for Asset Management (IAM, 2015) and Asset Capability Concept Model (AMC, 2014).

Despite the availability of these specialized models in the AM context, there is no prescription to improve the AM process by focusing on the regulatory framework compliance. To fill this gap, this research proposes a conceptual **Regulation-Oriented Model for Asset Management** – **AM-RoM** to offer methodological support for organisations to better deal with this issue.

AM-RoM does not aim to compete with established AM models, but rather offer a decision-making tool for the incremental improvement of the AM process in multi-asset

organisations with a focus on regulation. This conceptual model was built from an integrated analysis of the set of ISO 55001:2014 and ISO 31000:2018 standards (ISO, 2014b; ISO, 2018; LIMA; de LORENA; COSTA, 2018). It was designed with seven key actions, having the flexibility to be adapted to the scope of the regulatory requirements the organisation must be compliant with.

AM-RoM considers a descriptive statistical representation of the integrated view of the experts' perceptions, which is supported by their knowledge and experience[6]. It encompasses a Multi-criteria Decision Method (MCDM), based on the aggregation of the experts' knowledge to support the organisation in designing action plans for improving the AM process. The main idea is to offer a flexible tool to prioritize AM&RM ISO requirements, based on their degree of implementation and on the contribution, they offer to the organisation in meeting the regulatory requirements.

The relevance of the Model is its support to ISO 55001:2014 Improvement requirement, sub-item Continual improvement: "The organization shall continually improve suitability, adequacy and effectiveness of its asset management and asset management systems" (ISO, 2014b), and a closer observance of risk and regulation. To put it simply, it is the search for a model to give value to the assets not only from a technical point of view but also from a Regulatory point of view considering the current context of the organisation.

The AM-RoM proposes a solution to a real problem faced by highly regulated organisations, such as utilities. It considers a balance between academic approach and practical application, based on the judgment of experts. The Model was validated in a Brazilian company from the Power Transmission Sector. The systems of this sector require high safety and reliability and consequently, large investments in physical assets are essential. In addition, the Power Transmission Sector must meet strict regulatory requirements, which may sometimes come into conflict with the asset management view in a given context. The results can be used by managers to define intervention policies to improve the performance of the assets and asset management.

## 4.2 MODEL STRUCTURE

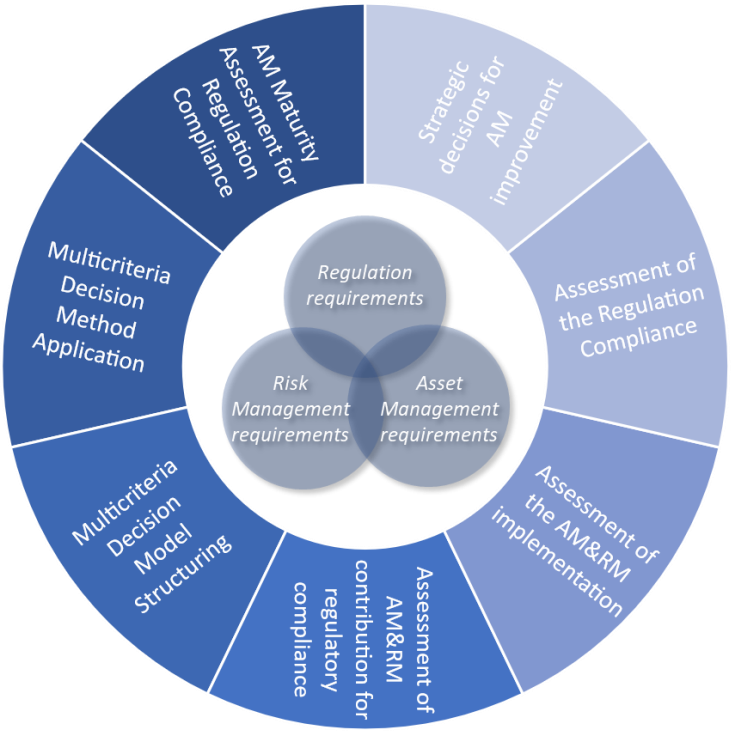
The AM-RoM, Figure 16, aims to provide AM process improvement, in a multifunctional and comprehensive way, considering two types of requirements: structuring

[6] In this chapter, 'perception' and 'knowledge' are used interchangeably.

and mandatory. The first is related to Asset and Risk Management and the second to the regulatory framework.

While the structuring requirements were previously identified through a joint analysis of ISO 31000:2018 (guidelines to risk management), and ISO 55001:2014 (asset management), by analysing the compatibility between the two standards (LIMA; de LORENA; COSTA, 2018), the mandatory requirements shall be evidenced *a posteriori* from a set of regulatory norms whose scope must be strategically defined to enable the application of the Model in a particular sector of the economy.

Figure 16 - Regulation-Oriented Model for Asset Management – AM-RoM




Source: Lima and Costa (2019)

AM-RoM was designed to be prescriptive in describing how to improve the AM process and it is justified in practice by providing actions to:

- Contribute to the strategic alignment of the AM process with business, aiming the organisation results improvement.
- Subsidize the implementation of action plans, identifying priority actions to the organisational context.
- Integrate the several multifunctional areas of the organisation towards a common goal.

- Identify priorities to provide asset management with effective control and governance of assets which is "essential to realize value through risk and opportunity" (ISO, 2014a), which contributes to promoting the efficiency and effectiveness of the assets.
- Meet the stakeholders' expectations by adding value to assets based on compliance with international standards in AM and RM as well as compliance with the regulation.
- Stimulate the increase of the decision-making efficiency with the prioritization of the essential requirements to the current organisational context, through the application of a multicriteria decision model.
- Assess the maturity of the AM process, focusing on Regulation considering international standards.
- Comply with ISO 55000:2014 "Continual improvement" requirement (ISO, 2014a).

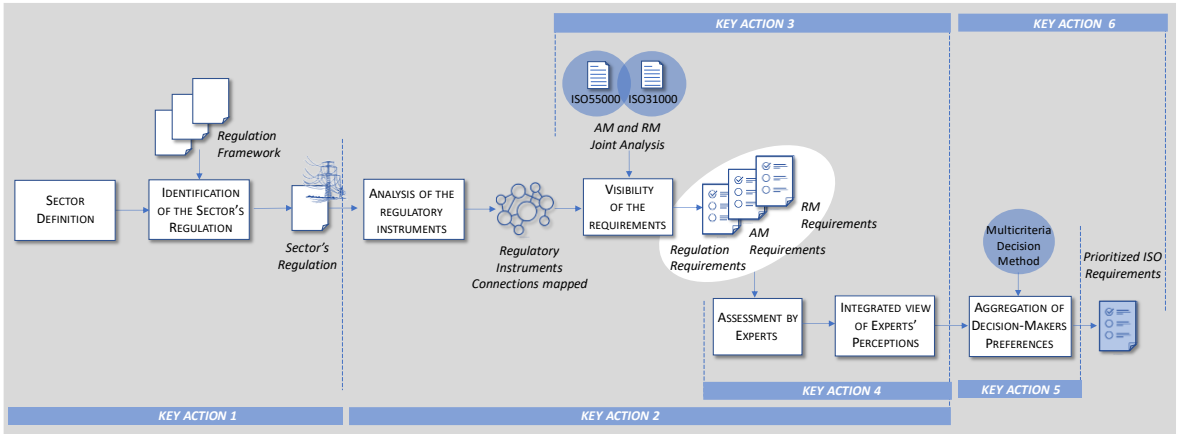
The components of the model are structured with seven key actions (KA) represented in a circular and sequential view, including:

- KA 1. Strategic decisions for AM improvement.
- KA 2. Assessment of the Regulation Compliance.
- KA 3. Assessment of the AM&RM implementation.
- KA 4. Assessment of AM&RM contribution for regulatory compliance.
- KA 5. Multicriteria Decision Model Structuring.
- KA 6. Multicriteria Decision Method Application.
- KA 7. AM Maturity Assessment for Regulation Compliance.

In the Model's internal layer three key-elements are integrally represented: Regulation framework; AM standard requirements; and RM standard requirements. In the following items, each of the key actions is detailed along with the pertinent key-elements. Figure 17 illustrates the process for key action 1 to 6.

It is important to notice that the activities of AM-RoM process, as represented in Figure 17, maybe associated with more than one key action in Figure 16. For example, the 'assessment by experts' activity in Figure 17 refers to 'assessment of the regulatory compliance' (key action 2), 'assessment of the AM&RM ISO requirements implementation' (key action 3), and 'assessment of AM&RM contribution to the regulatory compliance' (key action 4).

Figure 17 - AM-RoM process




Source: Lima and Costa (2019)

To make a clear connection between the activities shown in Figure 17 and the key actions detailed in the next items, an explicit association is shown in Table 13.

Table 13 - Process' elements versus key actions

| PROCESS' ELEMENTS (FIG. 17) | KEY ACTIONS (FIG. 16) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Sector definition | x | | | | | |
| Identification of the sector's regulation | x | | | | | |
| Analysis of the regulatory instruments | | x | | | | |
| Visibility of the requirements | | x | x | | | |
| Assessment by experts | | x | x | x | | |
| An Integrated view of experts' perceptions | | x | x | x | | |
| Aggregation of decision-makers' preferences | | | | | x | x |
| Multicriteria decision method | | | | | x | x |
| Prioritized ISO requirements | | | | | | x |

Source: Lima and Costa (2019)

### 4.2.1 Strategic decisions for Asset Management improvement

This key action defines the strategic decisions that can impact the execution of AM-RoM:

i. Context – Contextualize the Sector where the organisation operates.

ii. AM Goal Statement – Defines what the organisation wants to achieve by means of AM. All actions outlined during the execution of the Model should be in line with the stated objective.

iii. Scope of the AM-RoM – consists of the explanation of the regulated Sector and the definition of the Regulatory scope, input for the 'Assessment of the Regulation Compliance' key action.

iv. Actors, roles and responsibilities – Determines the professionals that will participate in the implementation of AM-RoM, their roles and responsibilities, depending on the organisation's strategy and structure. The most important actors are: the high management, the AM´s leader, the Regulation´s leader, and the AM and Regulation experts. Some responsibilities for each role are shown in Table 14.

Table 14 - Roles and responsibilities

| ROLES | RESPONSIBILITIES |
|---|---|
| Sponsor | Guarantee the strategic alignment.<br>Guarantee multidisciplinary involvement.<br>Mitigate the difficulties that may arise in the implementation of the Model. |
| Decision maker (DM) | The decision on the best investment option to implement the AM&RM ISO requirements.<br>Establish the importance of the criteria for AM&RM ISO requirements evaluations |
| Articulator | Guarantee the multifunctional participation of the different business areas involved in the AM process. |
| Communicator | Dissemination of results in order to strengthen the theme of AM improvement. |
| Expert | Evaluation of the AM&RM ISO structuring requirements and mandatory Regulation requirements |

Source: Lima and Costa (2019)

v. Fundamental objectives and criteria – Define objectives that are translated into criteria by which the AM&RM ISO and Regulatory requirements will be evaluated. As stated by de Almeida et al. (2015) the fundamental objectives are obtained from the questions related to the research process. In this case, it should be: 'What are the main aspects that should be analysed regarding the AM Goal Statement (Item 4.2.1.ii), considering the current context of the organisation?'. The criteria in AM-RoM were pre-defined to attend the main aspects: Analysis of the current level of regulatory compliance; Analysis of the degree of implementation of AM standards; Diagnosis of the contribution of AM practices to compliance with Regulation. The criteria favours the preference of an AM&RM ISO requirement in a pair-to-pair comparison.

### 4.2.2 Assessment of Regulation Compliance

In this key action, a categorization according to regulation similarity is proposed. Even delimited by the scope defined in the previous key action, due to the wide scope of the Regulation, it is necessary to identify and analyse, map their connections for the sector under study, and thus give visibility to the requirements through a categorization.

The analysis of the regulation is only possible if it is instantiated in each context, given the differences and peculiarities that exist in the regulation of the different sectors of the economy of each country. In this research, the Brazilian Regulatory framework is shown as an illustration through the application of AM-RoM performed in a Brazilian Power Transmission Enterprise described in Item 4.3. This key action includes:

i. Analysis of the Regulatory framework.
ii. Mapping the connections between the regulation standards and rules.
iii. Categorization of the Regulation requirements.
iv. $\boldsymbol{C_{kj}}$ **- Compliance degree**: Evaluation based on *j* experts' perceptions (*j* varying from 1 to *n*) of how much each *k-th* regulation requirement (*k* varying from 1 to *q*) is being met by the organisation in the current context, in a 0% to 100% scale, or 'no information' in case the expert does not have enough information about the status of a requirement and is not comfortable to answer.
v. $\boldsymbol{M_j\,[C_{kj}\,]}$ **- Integrated view of compliance degree**: Integrated view of $C_{kj}$, represented by the $C_{kj}$ average.

$$M_j\,[C_{kj}\,] = \frac{\sum_{j=1}^{n} C_{kj}}{n} \qquad (1)$$

As the experts' perceptions are expected to be not uniform in view of different experiences in distinct regulation´s aspects, and because the search for consensus through an aggregation method, would be quite difficult to achieve, the integrated view by means of descriptive statistics using the average allows the organisation to observe the information in a less imprecise way.

The 'Integrated view of compliance degree – $M_j\,[C_{kj}\,]$', Figure 18, is used to compose the indicator 'Integrated view of non-compliance Regulation – $W[R_{ijk}]$' further explained in Item 4.2.4 iii.

### 4.2.3 Assessment of the implementation of the AM&RM requirements

This key action uses AM and RM requirements as the input obtained from ISO 55001:2014 (Asset management — Management systems — Requirements) and ISO

31000:2018 (Risk Management Guidelines). The first comprises: Context of the organisation, Leadership, Planning, Support, Operation, Performance Evaluation and Improvement. The second composes Risk Management Framework (Leadership & Commitment; Integration; Design; Implementation; Evaluation; Improvement) and Risk Management Process. (Communication and Consultation; Scope, context, criteria; Risk assessment; Monitoring and Review; and Recording and Reporting). The key action includes:

Figure 18 - Evaluations Integrated View

| EVALUATIONS INTEGRATED VIEW | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $\frac{\sum_{j=1}^{n} C_{1j}}{n}$ | $\frac{\sum_{j=1}^{n} C_{2j}}{n}$ | | $\frac{\sum_{j=1}^{n} C_{kj}}{n}$ | | $\frac{\sum_{j=1}^{n} C_{qj}}{n}$ | $\leftarrow \boldsymbol{M_j[C_{kj}]}$ |
| | $\boldsymbol{M_j[I_{ij}]}$ | $Reg_1$ | $Reg_2$ | ... | $Reg_k$ | ... | $Reg_q$ | $\boldsymbol{W[R_{ijk}]}$ |
| $ISO_1$ | $\frac{\sum_{j=1}^{n} I_{1j}}{n}$ | $R_{1j1}$ | | ... | | ... | | |
| $ISO_2$ | $\frac{\sum_{j=1}^{n} I_{2j}}{n}$ | $R_{2j1}$ | | ... | | ... | | |
| | | | | ... | | ... | | |
| $ISO_i$ | $\frac{\sum_{j=1}^{n} I_{ij}}{n}$ | $R_{ij1}$ | | ... | $R_{ijk}$ | ... | $R_{ijq}$ | $R_{ijk}$*(1-$M_j[C_{kj}]$) |
| | | | | ... | | ... | | |
| $ISO_m$ | $\frac{\sum_{j=1}^{n} I_{mj}}{n}$ | $R_{mj1}$ | | ... | | ... | | |

Source: Lima and Costa (2019)

i. Identification of AM and RM requirements jointly analysed[7] (LIMA; de LORENA; COSTA, 2018).

ii. $\boldsymbol{I_{ij}}$ **- Implementation degree**: Evaluation based on *j* experts' perceptions (*j* varying from 1 to *n*) of how much each *i* AM&RM ISO requirement (*i* varying from 1 to *m*) is implemented by the organisation in the current context, in a 0% to 100% scale, or 'no information' in case the expert does not have enough information about the status of a requirement and is not comfortable to answer. Management practices act as a proxy for ISO requirements because not all organisations have AM and RM in a structured way, or they are not familiar with the international standards terminology.

iii. $\boldsymbol{M_j\,[I_{ij}\,]}$ **- Integrated view of Implementation degree**: Integrated view of $I_{ij}$ represented by $\boldsymbol{I_{ij}}$ average.

[7] Refers to Table 10 in Chapter 3.

$$M_j\,[I_{ij}\,] = \frac{\sum_{j=1}^{n} I_{ij}}{n} \qquad (2)$$

The justification for the average is the same as in Item 2.2.v.

### 4.2.4 Assessment of the AM&RM requirements contribution for regulatory compliance

The objective of this key action is to evaluate the contribution of the ISO requirements concerning Regulation compliance. This key action includes:

i. $\boldsymbol{S_{ijk}}$ **– Support for Regulation compliance**: Evaluation by *j* experts (*j* varying from 1 to *n*) of the contribution given by *i* AM&RM ISO requirement (*i* varying from 1 to *m*) for compliance to the *k* Regulatory requirement (*k* varying from 1 to *q*) in the organisation´s current context. Evaluation 1 is a favourable assessment and means that *i* AM&RM ISO requirement contributes significantly, evaluation 0 means it does not contribute or contributes in an insignificant way, and 'no information' in case the expert does not have enough information about the requirement´s status and is not comfortable to answer.

ii. $\boldsymbol{R_{ijk}}$ **- Proportion of favorable evaluations to Regulation**: the proportion of favorable assessment, based on *j* experts, of $ISO_i$ contribution for the compliance with *k* regulatory requirement (considering the total of the valid evaluations in case there is information to judge). The set of $R_{ijk}$ values constitutes a matrix with *i* x *k* elements.

$$R_{ijk} = \begin{cases} \left[\sum_{j=1}^{n} a_{ijk}\right] / \left[\sum_{j=1}^{n} b_{ijk}\right], \text{if } \sum_{j=1}^{n} b_{ijk} \neq 0 \\ 0, \text{ if } \sum_{j=1}^{n} b_{ijk} = 0 \end{cases} \qquad (3)$$

$$a_{ijk} = \begin{cases} 1, & \text{if } S_{ijk} = 1 \\ 0, & \text{otherwise} \end{cases}$$

$$b_{ijk} = \begin{cases} 1, & \text{if } S_{ijk} = 0 \text{ or } 1 \\ 0, & \text{otherwise} \end{cases}$$

Note that $a_{ijk}$ are the favorable evaluations while $b_{ijk}$ are all the experts' valid evaluations, favourable (1) or not (0), that is, when there is information to judge.

iii. $\boldsymbol{W[R_{ijk}]}$ **- Integrated view of non-compliance Regulation**: Integrated view of $R_{ijk}$ represented by $R_{ijk}$ matrix (*i* x *k*) multiplied by the vector (*k* x *1*), which is the complement of $M_j\,[C_{kj}\,]$:

$$W[R_{ijk}] = R_{ijk} * \left(1 - M_j\,[C_{kj}\,]\right) \qquad (4)$$

It should be noted that the 'Proportion of favourable evaluations to Regulation – $R_{ijk}$ , component of the 'Integrated view of non-compliance Regulation– $W[R_{ijk}]$' indicator is non-

zero in situations where at least one of the evaluators considers that the AM&RM ISO requirement contributes favourably to meeting the regulatory requirement in the analysis ($S_{ijk}$ = 1; $a_{ijk}$ = 1; $b_{ijk}$ = 1).

As can be seen in subitem ii, the $R_{ijk}$ component comprises the proportion of the total of the favourable assessments in relation to the total of the valid assessments. Valid assessments are those in which experts assess whether the AM&RM ISO requirement contributes to the compliance of the regulatory requirement *($S_{ijk} = 1$)* or does not contribute *($S_{ijk} = 0$)*, therefore the assessments in which experts are not comfortable to express their perception (they don't have enough information) are not considered.

The $\left(1 - M_j\,[C_{kj}\,]\right)$ component of the non-compliance indicator $W[R_{ijk}]$ is the weighting element of component $\boldsymbol{R_{ijk}}$**.** This weighting element represents what is missing so that the regulatory requirement is fully met by the organisation, in the integrated view of the experts' perceptions. That is, the more non-compliance of the regulatory requirement, the greater the non-compliance indicator $W[R_{ijk}]$.

It is important to emphasize that what is missing for the k regulatory requirement to reach 100% of compliance, given by the complement of $M_j\,[C_{kj}\,]$, is a measure of the degree of achievement, and not the necessary effort for the compliance.

### 4.2.5 Multicriteria Decision Model Structuring

This key action is responsible for the modelling of the multicriteria decision problem and for the aggregation of the decision-makers' preferences, as well as the selection of the multicriteria Method. The procedures for this key action are adapted from de Almeida et al. (2015).

Based on the evaluations by the AM and Regulation experts, obtained in the previous key actions, a consequence matrix can be built, as shown in Table 15, where the space of actions is discrete and comprises the *m* AM&RM ISO structuring requirements that are been evaluated under $M_j\,[I_{ij}\,]$ and $W[R_{ijk}]$ , the integrated view of AM&RM ISO requirements implementation degree and Regulation compliance, respectively.

In this key action, some assumptions are made for the preference modelling and the method selection to solve the multicriteria decision problem. Concerning the preference modelling it is assumed a non-compensatory approach, meaning that the trade-off between the criteria is not considered. In other words, the performance from an alternative in one criterion is not compensated by better performance on other criteria and the weights *w1* and *w2* are the

importance given by the decision-maker to the criteria, representing their relative importance, the sum shall be equal to 1 (one).

Table 15 - Consequence Matrix

| | CRITERIUM 1: Implementation - $w_1$ | CRITERIUM 2: Support for Regulation compliance - $w_2$ |
|---|---|---|
| $ISO_1$ | $M_j\,[I_{1j}\,]$ | $W[R_{1jk}]$ |
| $ISO_2$ | $M_j\,[I_{2j}\,]$ | $W[R_{2jk}]$ |
| . . | . . | . . |
| $ISO_i$ | $M_j\,[I_{ij}\,]$ | $W[R_{ijk}]$ |
| . . | . . | . . |
| $ISO_m$ | $M_j\,[I_{mj}\,]$ | $W[R_{mjk}]$ |

Source: Lima and Costa (2019)

When the problem involves more than one decision-maker it is necessary to apply an aggregation procedure to reduce the set of individual preferences to a collective preference. Two forms of aggregation scientifically accepted are: aggregation of the initial preferences of the decision-makers (aggregation in the process input) and aggregation of the ranking of the alternatives, defined by each decision-maker (aggregation in the process output). In the first case, the process does not seek the true solution, but rather the most appropriate solution, considering the preferences of the Decision Makers (DM). In the second case, the ranking of alternatives produced individually by each decision-maker is submitted, for example, to a voting aggregation process (de ALMEIDA et al., 2015).

The choice between the two methods of aggregation depends on the context of the organisation, its power structure, the profile of the decision-makers and the characteristic of the problem in question.

Concerning to the method selection, since the problem is the AM&RM ISO requirements ranking, the multicriteria method must generate a complete previous order among the alternatives. An out-ranking method like PROMETHEE II (The Preference Ranking Organisation METHod for Enrichment of Evaluations) is quite adequate, provided that it deals with ranking problems in a non-compensatory preference modelling, besides being easily understood by the decision-maker (BRANS; de SMET, 2016). Although AM-RoM has incorporated PROMETHEE II, other out-ranking multicriteria methods can be used, for example, ELECTRE II – Elimination Et Choix Traduisant la Réalité (de ALMEIDA et al., 2015).

### 4.2.6 Multicriteria Decision Method Application

In this key action, the ranking problem evaluated by AM-RoM is summarized through the following question: Which are the priority AM&RM ISO requirements to be implemented considering the organisation´s necessity to be compliant with the Sector Regulation? The answer is obtained by performing a multicriteria analysis to rank the AM&RM ISO requirements, using the method suggested in the previous key action.

PROMETHEE works with six preference functions or general representations for evaluating criteria. The criteria are represented by the usual function *Pt* in the intra-criteria evaluation. Comparing the alternatives (AM&RM ISO requirements) pair to pair, for each criterion, the function of the difference between the performance of the $ISO_x$ and $ISO_y$ requirements is given by:

$$g_t(ISO_x) - g_t(ISO_y) > 0 \Rightarrow P_t(ISO_x, ISO_y) = 1 \quad (5)$$

$$g_t(ISO_x) - g_t(ISO_y) \leq 0 \Rightarrow P_t(ISO_x, ISO_y) = 0 \quad (6)$$

Thus, it is possible to assign an out-ranking degree for each pair of ISO requirements: given by:

$$\pi_t(ISO_x, ISO_y) = \sum_{t=1}^{z} P_t(ISO_x, ISO_y) w_t \quad (7)$$

$$\pi_t(ISO_y, ISO_x) = \sum_{t=1}^{z} P_t(ISO_y, ISO_x) w_t \quad (8)$$

The first is the out-ranking degree of $ISO_x$ over $ISO_y$ and the second is the out-ranking degree of $ISO_y$ over $ISO_x$.

Since there are *m* AM&RM ISO requirements options for the problem, each of them relates to other *m*-1 options. The positive and negative over-classification flows are then defined as:

$$\phi^+(ISO_x) = \frac{1}{m-1} \sum_{ISOx} \pi(ISO_x, ISO_i) \quad (9)$$

$$\phi^-(ISO_x) = \frac{1}{m-1} \sum_{ISOx} \pi(ISO_i, ISO_x) \quad (10)$$

The net out-ranking flow is defined as:

$$\phi(ISO_x) = \phi^+(ISO_x) - \phi^-(ISO_x) \quad (11)$$

The positive out-ranking flow [$\phi^+$ *($ISO_x$)*] represents the intensity degree of $ISO_x$ over the remaining alternatives, while the negative out-ranking flow [$\phi^-$ *($ISO_x$)*] represents the intensity of preference of all alternatives over $ISO_x$.

The PROMETHEE II GAIA software calculates the net flows for each of the alternatives based on the weighs and consequences shown in Table 15. The higher the net flow, the higher is the AM & RM ISO requirement priority.

The output of the ‘Multicriteria Decision Method Application’ key action is the list of AM&RM ISO structuring requirements. These requirements are prioritized according to their implementation degree in the organisation, as well as their contribution to meeting the Regulatory requirements. The implementation of the prioritized requirements should improve the AM process.

### 4.2.7 AM Maturity Assessment for compliance with Regulation

There are several stages in the evolution of process maturity. It is essential to realise the level they are in as a starting point for defining the strategy for driving improvement. Since the Asset Management process of organisations is in one of these levels, therefore, specific actions are necessary because the required initiatives to improve it will be different due to different contexts. In order to characterize the stage of the process’s maturity, it is necessary to define and evaluate criteria periodically.

Good practice indicates that evolution occurs in stages, from the first to the second level, from the second to the third level, and so on. So, it is important to know the defined maturity levels and improve them in a planned way. The maturity of the process goes from ad-hoc initiatives, where the AM process contributes little to the organisational performance until the last stage where the results obtained contribute to the business effectively. Moving from one stage to another requires a substantial change in the way the process is performed. Planning is needed to induce significant improvements to leverage better results. From the implementation of an action plan, the maturity of the process is raised to a new level, adding greater value to stakeholders.

An AM Maturity Assessment model for compliance with Regulation is justified because it complies with ISO 55000: 2014 (´Performance evaluation´ item, ´Monitoring, measurement, analysis and evaluation´ sub-item), which requires the organisation to determine: "what needs to be monitored and measured; the methods for monitoring, measurement, analysis and evaluation, as applicable, to ensure valid results; when the monitoring and measuring shall be performed; and when the results of monitoring and measurement shall be analysed and evaluated" (ISO, 2014b). Nevertheless, the detailing of this instrument is not part of the scope of this research, because this AM-RoM key action is still under development.

## 4.3 AM-RoM APPLICATION IN ELECTRIC TRANSMISSION ENTERPRISE

The AM-RoM was applied to the Brazilian Electric Energy Transmission Enterprise – BEETE, a made-up name of the Brazilian organisation, due to the need for information confidentiality. The study was carried out with the sponsorship of the Operations Director who is responsible for the Asset Management and Regulation areas.

In this study, the consolidation of the scope and participation, as well as the conditions of confidentiality were defined in a meeting with the sponsor.

Amongst the company's professionals, 28 were identified as having recognized experience and expertise in one of the areas bellow:

i. Asset Management.
ii. One or more processes of the Asset Life Cycle (ALC) of the Electric Power Transmission Sector.
iii. The Electric Power Transmission Sector Regulation.

It's important to highlight that all the potential respondents were ratified by the Operations Director and the participation was voluntary.

To accomplish the research the 28 experts were contacted and of these, 14 responded (50%). Although the sample was 50% of the intended universe, it is reasonable to affirm that the results are quite reliable and significant for the organisation, due to the careful selection of the respondents. They belong to the set of professionals who better know about the subject in the organisation and their voluntary participation has brought the necessary robustness to the result.

The professional of the highest hierarchical level among the 14 respondents was appointed by the Operations Director to be the decision-maker. As the Operations Director’s advisor has extensive experience and expertise in asset management, he was given the responsibility for the task of coordinating the research and making the decisions that were pertinent.

The structure of decision-maker preference in relation to the criteria involves a value judgment, which will be considered by the Multi-criteria Decision Method - MCDM. According to de Almeida et al., 2015, "These preferences consist of the DM’s subjective evaluation of the criteria. This subjectivity is an inherent part of the problem and cannot be avoided".

The data collection was based on 3 questions, as described in Items 4.3.2, 4.3.3 e 4.3.4, that required 16, 27 and 432 (27 x 16 matrix) evaluations respectively (the first two in percentual and the last in binary form), by means of an Excel spreadsheet. If the expert did not feel comfortable evaluating, he/she was oriented to give an explicit "no information" answer. Of the

14 questionnaires received, 14, 13 and 12 were considered valid for the first, second and third questions, respectively.

### 4.3.1 Strategic decisions for Asset Management improvement

#### 4.3.1.1 The organisation´s context in the economic sector

The supply of energy is an essential service of public utility for economic development and for society's quality of life. The Power Transmission System is part of the Electric Energy Sector and has a broad range of engineering assets. It demands the best management practices in order to guarantee that assets fulfil their purpose and have their useful lifetime extended if possible. In this way, the AM delivers value to the organisation, provides the economy and gives visibility to the stakeholders. Moreover, establishing, maintaining, and continuously improving a structured AM process, which simultaneously privileges RM and attends the Regulatory agencies' requirements, is the key to gather the maximum value and to maintain the organisation productively and sustainable.

As it is an engineering-related sector, the assets of the Power Transmission System have characteristics of: expensiveness, which demands strong asset governance; complexity, because it deals with many technologies that work in an integrated way; broad impact on the enterprise, which requires synchronization of AM with other processes and effective visibility of asset information by multiple stakeholders; also extended lifetime of its assets, which need management and a continuous improvement process of asset life cycle performance (LIN, S. et al., 2007), and a necessity of a consistent IT support and decision tools for the management of the assets (SCHNEIDER, J. et al., 2006).

The Power Transmission System AM life cycle generally comprises the stages of prospecting, acquisition, design, construction, operation, maintenance, and disposal. The asset´s life cycle is the aim of the AM process where output depends on the information that flows through all stages (LIN, S. et al. 2007). In turn, each stage has specific peculiarities and is impacted by the AM and RM requirements and must be managed to be compliant with the Electric Energy Sector Regulation.

In Brazil, Power Energy Sector´s regulatory framework is the responsibility of *Agência Nacional de Energia Elétrica* – ANEEL, which is the Brazilian electricity regulatory agency. The regulatory framework covers topics related to the Generation, Transmission, Distribution and Commercialization of energy, and involves Tariff Regulation Procedures (*Procedimentos*

*de Regulação Tarifária* – PRORET), Technical Notes, Normative Resolutions, Homologated Resolutions, among others.

#### 4.3.1.2 Statement of Asset Management Purposes

BEETE´s goals statement or purposes it wants to achieve through AM were defined as:

- To subsidize strategic decisions on the asset portfolio in order to contribute to a conscientious selection of a set of integrated projects and actions, aiming to add value, minimize risks and achieve economic sustainability resulting from effective portfolio management and concession contracts.
- To provide structured coordination of integrated management, engineering, operation, maintenance, finance, supplies and related areas with the objective of increasing the efficiency of the Organisation, which can be reflected in the comparison between the companies in the Sector.

#### 4.3.1.3 Definition of the AM-RoM Scope

The Scope of the AM-RoM, for the purpose of this application, was defined by the Transmission regulation standards and rules shown in Table 16 specifically in the asset's reinforcements and improvements of the Transmission area (ANEEL, 2018b).

Table 16 - Scope of transmission regulation standards

| TRANSMISSION REGULATION: REINFORCEMENTS & IMPROVEMENTS[8] | |
|---|---|
| RN 443/2011 updated by RN 643/2014 | It distinguishes between improvements and reinforcements in transmission facilities under the responsibility of transmission concessionaires and gives other measures |
| RN 454 2011 | Establishes the criteria and conditions for the commercial start-up of reinforcements and expansions of transmission facilities to be integrated into the National Integrated System - SIN. |
| PRORET 9.3 | Annual adjustment of the transmission concessionaires´ revenues |
| PRORET 9.7 | Implementation of improvements and reinforcements in installations under the responsibility of transmission concessionaires |
| PRORET 10.4 | Readjustment of the revenues of transmission concessionaires |

Source: Lima and Costa (2019)

[8] Improvement is the installation, replacement, or refurbishment of equipment in existing transmission facilities, or the adequacy of these facilities, to maintain the provision of adequate electricity transmission service. Reinforcement is the installation, replacement, or refurbishment of equipment in existing transmission facilities, or the adequacy of these facilities, aiming at increasing transmission capacity, increasing the reliability of the National Interconnected System - SIN or connecting users (ANEEL, 2011).

Table 17 - Roles and responsibilities

| ROLES | RESPONSIBILITIES | ACTORS | | | |
|---|---|---|---|---|---|
| | | D | R | L | E |
| Sponsor | Guarantee the Strategic Alignment | x | | | |
| | Guarantee multidisciplinary involvement. | x | x | | |
| | Mitigate the difficulties that may arise in the Model implementation | x | x | | |
| | Validate the AM-RoM results | x | | | |
| Decision maker | Establish the importance of the criteria for assessing ISO requirements to meet regulatory requirements | | | x | |
| Articulator | Guarantee the multifunctional participation of the different business areas involved in the Asset Management process. | | x | | |
| Communicator | Dissemination of results in order to strengthen the theme in the company. | x | x | x | |
| | Dissemination of the culture of Asset Management improvement. | x | x | x | x |
| Expert | Evaluator of the ISO structuring requirements and Regulation mandatory requirements | | x | x | x |

Source: Lima and Costa (2019)

#### 4.3.1.4 Actors, roles and responsibilities

The professionals' performance and responsibilities related to the implementation of AM-RoM in BEETE are shown in Table 17, where D- stands for Director, R-Director Representant, L-Asset Management leader or Regulation Leader, and E-Experts.

#### 4.3.1.5 The Fundamental objectives and criteria

The criteria defined in Item 4.2.1.v and the weights given by the decision-maker are shown in Table 18. The criterium 'Degree of Compliance' is used to weight the criterion 'Support of AM&RM to Regulation', as detailed in Item 4.2.4.iii.

The weights express the decision-maker preference based on the following question: "Considering the need of prioritizing the most relevant AM&RM ISO requirements for the organisation to be compliant with the Regulation, assign a weight considering the importance of the two criteria:

Table 18 - Criteria and weights

| CRITERIA | DESCRIPTION | WEIGH |
|---|---|---|
| Degree of Compliance | Analysis of the current level of regulatory compliance | - |
| Degree of Implementation | Analysis of the degree of implementation of Asset Management standards | 0,4 |
| Support of AM&RM ISO to Regulation compliance | Assessment of the contribution of AM practices with the organisation to be in compliance with Regulation | 0,6 |

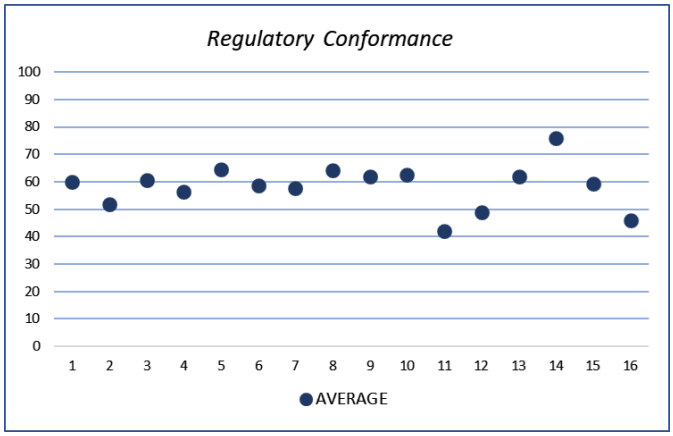
Source: Lima and Costa (2019)

- Degree of implementation of the current management practices in the Organisation, equivalent to ISO 55001 - AM and ISO 31000 – RM (instantiated in the AM process). The lower means that the Organisation is not mature enough about the implementation of management practices.
- Support to Regulation Compliance (contribution of management practices to the Organisation be compliant with Regulation). The greater support means that the requirement under analysis is relevant for compliance with the Regulation, that is, its implementation in a structured way would increase the Organisation's ability to meet regulatory requirements regarding Reinforcement and Improvement of the Transmission function.

### 4.3.2 Assessment of the Regulation Compliance

The evaluation of how the organisation meets the regulatory framework was obtained through the following query to experts: ‘On the basis of your experience/knowledge what is your perception of the extent to which the Regulatory requirement is being addressed by the Organisation in the current context? Assign a value of 0% (not met) to 100% (fully met). In answering this question, consider that the information under analysis refers to professionals who should be fully aware of the requirements, because of their role in the company, and will act as required by the Regulation’. The integrated view of the expert´ evaluations for each Regulation requirement was obtained from the average of the evaluations, as explained in Item 4.2.2. The result represented by the evaluation´s average of the 16 regulatory requirements conformance is shown in Figure 19.

Figure 19 - Assessment of the Regulation Compliance




Source: Lima and Costa (2019)

The respondents stated that most regulatory requirements (12 from 16) are, on average, at a compliance degree of around 60% or more. A significant difference between the minimum and maximum evaluations is visually observed in practically all requirements, leading to the assumption that there is no uniformity of the experts´ perceptions regarding Regulation compliance. Non-uniformity is probably because they work in different areas of the organisation and have different backgrounds. This should be explored, by the organisation in the improvement of the AM process.

The results provide interesting data about regulation compliance. The organisation should investigate the relation between 'different knowledge and experience' and 'different perceptions' to enhance an asset management levelling plan. However, this was not an objective considered in this study.

### 4.3.3 Assessment of the AM&RM implementation

The Assessment of the AM&RM ISO requirements was obtained through the following query: 'On the basis of your experience/knowledge, what is your perception of the extent to which management practices (equivalent to ISO55001 and ISO31000) are implemented in the Organisation? Assign a value of 0% (not implemented) to 100% (fully implemented)'. The integrated view of the expert´s evaluations for each AM&RM ISO requirement was obtained from the average of the evaluations, as explained in Item 4.2.3, and the results $\boldsymbol{M_j}\,[\boldsymbol{I_{ij}}]$ are shown in the Matrix of Consequences, Table 19.

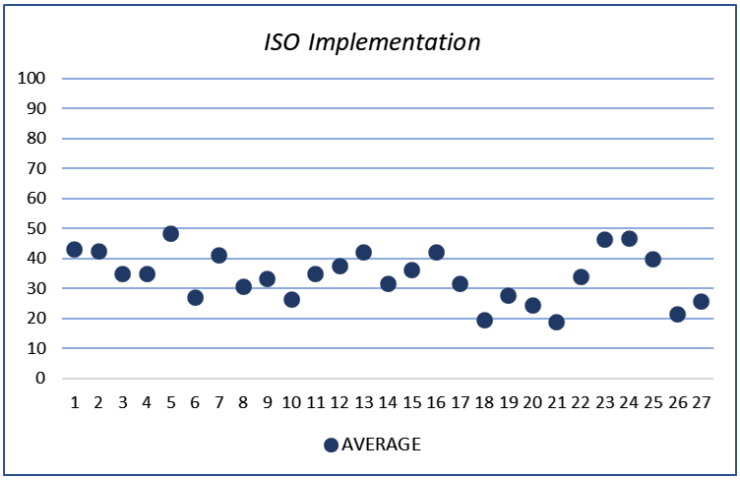
Table 19 - Matrix of Consequences

| AM&RM | $M_j[I_{ij}]$ | $W[R_{ijk}]$ | AM&RM | $M_j[I_{ij}]$ | $W[R_{ijk}]$ | AM&RM | $M_j[I_{ij}]$ | $W[R_{ijk}]$ |
|---|---|---|---|---|---|---|---|---|
| **1** | 43,08 | 3,94 | **10** | 26,54 | 4,45 | **19** | 27,78 | 2,33 |
| **2** | 42,50 | 4,14 | **11** | 35,00 | 3,48 | **20** | 24,55 | 2,85 |
| **3** | 35,00 | 2,87 | **12** | 37,50 | 4,37 | **21** | 19,00 | 2,93 |
| **4** | 35,00 | 3,32 | **13** | 42,31 | 4,64 | **22** | 34,00 | 2,63 |
| **5** | 48,33 | 4,07 | **14** | 31,67 | 3,51 | **23** | 46,36 | 3,75 |
| **6** | 27,31 | 2,98 | **15** | 36,25 | 4,62 | **24** | 46,82 | 2,90 |
| **7** | 41,15 | 3,61 | **16** | 42,08 | 4,77 | **25** | 40,00 | 3,08 |
| **8** | 30,77 | 2,50 | **17** | 31,82 | 3,75 | **26** | 21,67 | 2,08 |
| **9** | 33,33 | 4,37 | **18** | 19,58 | 3,69 | **27** | 25,83 | 2,68 |

Source: Lima and Costa (2019)

The result shown in Figure 20 is represented by the average of the 27 AM&RM ISO requirements implementation degree. In an inverse way from the one obtained for the Assessment of the Regulation Compliance, the respondents stated that most AM&RM ISO requirements (18 from 27) are, on average, at an implementation degree of 40% or less. The result is a relevant contribution to be considered by the managers in the AM improvement process as it presents a significant difference in the experts' perceptions of how AM practices are implemented in the organisation.

Figure 20 - Assessment of AM&RM ISO Implementation degree




Source: Lima and Costa (2019)

### 4.3.4 Assessment of AM&RM contribution to Regulatory compliance

Following the steps in Item 4.2.4, the Assessment of AM&RM ISO requirement contribution to Regulatory compliance was firstly obtained from the expert´s evaluation through the following query: 'Based on your perception, do you realise that AM practices in the Organisation, equivalent to the ISO55001 (Asset Management) and ISO31000 (Risk Management) requirements contribute significantly to the compliance with the Regulatory requirement? Answer 1 if you think they contribute significantly, zero if you find that they contribute little or do not contribute, and 'no information' if you are not comfortable to evaluate'.

Secondly, for each AM&RM ISO requirement, the proportion of favourable evaluations regarding each Regulatory requirement was calculated from the total of valid evaluations, when there was enough information to draw on. Finally, the proportion of favourable evaluations was multiplied by the complement of the compliance degree of each Regulatory requirement. The results $\boldsymbol{W}[\boldsymbol{R_{ijk}}]$ are shown in the Matrix of Consequences in Table 19.

### 4.3.5 Multicriteria Decision Model Structuring

The integrated view of the evaluations of 27 AM&RM ISO requirements and the integrated view of their support to the 16 Regulatory requirements, based on experts' perceptions, are shown in the Matrix of Consequences, Table 19. They are the input to the Multi-criteria Decision Method Application.

In this study, regarding the aggregation of preferences (see detail in Item 4.2.5), it was an aggregation in the process input, with the alternatives and criteria agreed on by the Operations Director and his staff, in a face-to-face meeting. It was not necessary to reach a consensus about the weights of the criteria because there was only one decision-maker, as the Operations Director's advisor was delegated to make decisions within the scope of the research. Autocratic decisions are accepted in the business world where there is a hierarchy of power recognized in the organisation and this fits perfectly to the context of the case study.

### 4.3.6 Multicriteria Decision Method Application

The data in the Matrix of Consequences, Table 19, and the weights assigned by the decision-maker, Table 18, were input into PROMETHEE GAIA to calculate the net flow for each alternative, obtaining the AM&RM ISO requirements ranking. The results found are shown in Table 20.

Table 20 - The net flow result from PROMETHEE

| AM&RM | Ø | AM&RM | Ø | AM&RM | Ø | AM&RM | Ø |
|---|---|---|---|---|---|---|---|
| **16** | 0,8154 | **23** | 0,5000 | **11** | -0,0154 | **21** | -0,6308 |
| **13** | 0,8000 | **9** | 0,3308 | **4** | -0,0615 | **8** | -0,6615 |
| **5** | 0,6769 | **7** | 0,2308 | **14** | -0,1231 | **20** | -0,6769 |
| **2** | 0,6000 | **10** | 0,2124 | **18** | -0,2769 | **27** | -0,6923 |
| **15** | 0,6000 | **24** | 0,0923 | **3** | -0,2923 | **19** | -0,7385 |
| **1** | 0,5385 | **17** | 0,0692 | **6** | -0,4000 | **26** | -0,9385 |
| **12** | 0,5154 | **25** | 0,0154 | **22** | -0,4923 | | |

Source: Lima and Costa (2019)

The first five prioritized dimensions, considering the context of the studied organisation, correspond to:

- Support S6: Documented and controlled internal and external information to meet legal and regulatory requirements.
- Support S3: Professionals fully aware of their role in the Asset Management process.
- Leadership L1: Leadership and commitment of senior management regarding risk management integrated to the AM process, as well as the establishment of policies, resource allocation, and multi-functional collaboration.
- Context C2: Establishment of criteria for AM decision making in considering the needs and expectations of stakeholders.
- Support S5: 'Roles and responsibilities, the significance of risks, consistency and trace-ability of financial and technical data' clearly defined, in order to comply with legal and regulatory requirements.

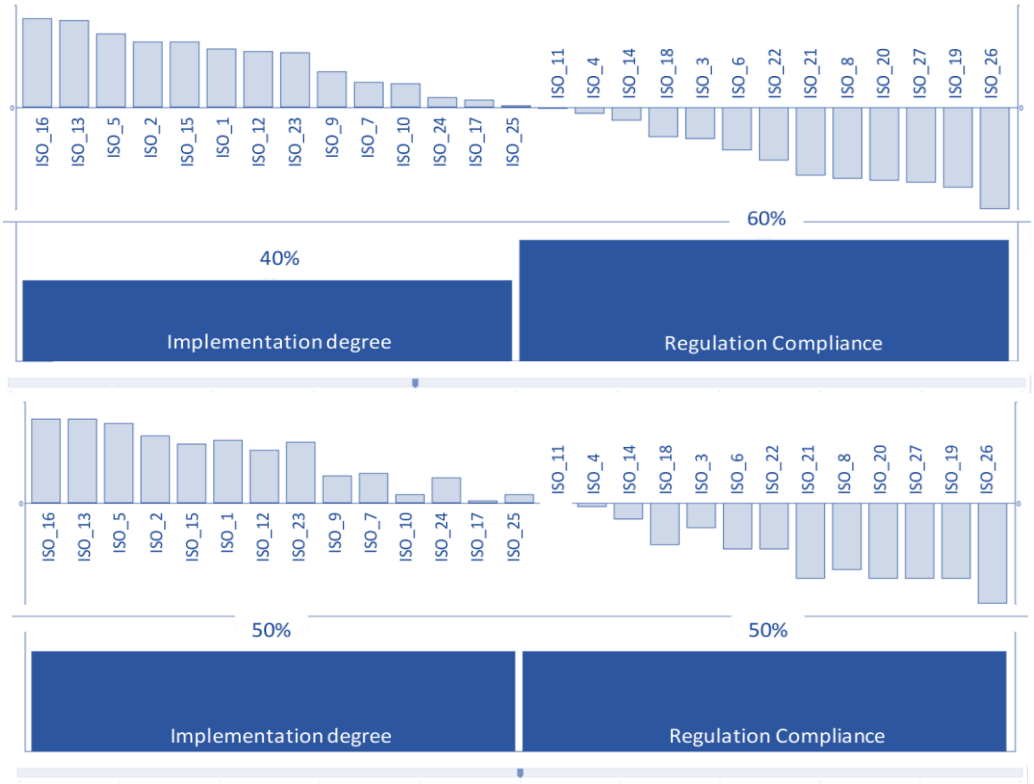
The results seemed quite significant for the organisation since it had just implemented a formal structure under the aegis of a common leadership for asset management and regulation. It is important to highlight that concerns about the regulatory issue appear explicitly in the first and fifth prioritized requirements, leading to the belief that the joint action of Asset Management and Regulation further strengthens the organisation to achieve its objectives.

### 4.3.7 Sensitivity Analysis

A sensitivity analysis reveals how effective a system is, by making explicit which variations of inputs affect the values of the outputs (ANDRES, 2010). One possibility for the sensitivity analysis is the variation of the input parameters, for example, the preference of the

decision-makers, which are the weights of the criteria. More robust forms than those used here, imply the variation of these weights up and down.

Figure 21 - Sensitivity Analysis




Source: Lima and Costa (2019)

During the individual analysis of decision-makers, the results indicated diversity between their preferences in judging the importance of the criteria. In this study, a simplified form of sensitivity analysis was adopted, equalizing the weights attributed by decision-makers both in relation to the implementation degree criterion as well as the regulation non-compliance criterion. The result presented a collective ranking with no significant differences in the order of the requirements.

Considering that the model does not incorporate uncertainties, all parameters are known, among them the criteria's weights. So, variations of the weights were performed to observe how much the response recommended by the model could be affected, that is, how much the Multi-criteria Decision model was sensitive to the change of the parameters. The results did not present significant changes in the order of prioritization of the requirements, as shown in Figure 21, verifying the robustness of the model.

## 4.4 FINAL CONSIDERATIONS

The problem addressed in this research fills a gap in the literature linking the theme of regulation with the discipline of asset management, in addition to considering relevant aspects of risk management. This is a matter of interest to multi-asset organisations operating under the strong control of regulatory agencies. The main objective is to contribute to these organisations' efforts to be in compliance with the regulation of the Sector in which they operate.

In this study, the Regulation-Oriented Model for Asset Management – AM-RoM is proposed as a decision-support tool, based on experts' perceptions which are supported by their knowledge and experience. The aim of the AM-RoM is the selection of AM&RM ISO standard requirements according to a ranking of priorities in order for the organisation to comply with regulatory requirements in the current organisational context.

How mature the organisation is in implementing the risk and asset structuring requirements and how much it meets the regulatory demands are identified through the application of the AM-RoM. It also identifies which of the AM&RM ISO requirements contribute more significantly to meeting the regulation. Algorithms are applied to obtain an integrated view of the experts' evaluations. In addition, the AM-RoM incorporates a multi-criteria decision model for prioritizing ISO structuring requirements of asset management and risk management.

Although AM-RoM can be applied in any regulated sector of the economy, a validation was performed in a Brazilian company in the Energy Transmission Sector. It was useful attaining insights for the prioritization of extremely important issues such as the need to structure the information to meet legal and regulatory requirements, make professionals fully aware of their role in the AM process, establish a committed leadership with RM integrated into the AM process, as well as with appropriate policies and multi-functional collaboration. The decision-maker expressed his personal impression with the results found: 'I think they are very interesting and consistent with my perception'.

Among the prioritized requirements is the need for the professional's awareness about their role in the asset management process; the establishment of policies; the resource allocation and the multi-functional collaboration to risk management integrated with the AM process. Multi-functional collaboration allows, for example, an easier identification of incorrect design and failure modes, which helps to avoid defects that make the system unsafe for the activity of the operator, also helps to improve the reliability of the system, preventing the interruption of its operation. It is up to the asset management process to determine which actions will be

implemented throughout the life cycle of the asset. For example, at the maintenance stage to propose policies under which maintenance management will be structured considering issues related to reliability, maintainability, availability and safety of the system.

For future studies, the development of an Asset Management Maturity Model which focuses on Regulation is suggested. Also, research to evaluate how the implementation of the ISO 55000: 2014 and ISO 31000: 2018 contributes to the organisation being more compliant, considering the hypothesis that the greater the degree of the structuring of the AM processes the greater the organisation's compliance with the regulatory framework of the sector in which it operates.

The models described in this chapter and in the previous one are different alternatives to support decisions in the implementation of AM and RM with a focus on Regulation. They were developed to meet the needs of an asset-intensive organization. In the next chapter, a model that serves a different purpose from the previous models is described. The purpose is to expand academic knowledge on a specific issue within the scope of AM. This issue, which is especially important for asset-intensive organizations, is about how AM relates to business.

# 5 ASSET MANAGEMENT AND BUSINESS PERFORMANCE RELATIONSHIP – AMBP MODEL

This chapter is extracted from the paper by Lima, McMahon and Costa (2020). The Asset Management and Business Performance Model (AMBP model) attend to the secondary objectives of the thesis: ‘To establish the premises for the relationship between AM and Business Performance, based on the literature’ and ‘To evidence the relationship between AM and business performance in asset-intensive organisations with the support of a conceptual model, based on AM case studies of many sectors of the economy and on the established premises’. It answers the second research question ‘How to evidence the relationship between AM and business performance in asset-intensive organisations?’.

## 5.1 CONTEXTUALISATION

In the infrastructure sector, asset-intensive businesses involve significant capital investment, and the effective management of the assets is essential for the achievement of business' goals. Asset Management (AM) is a core function of asset-intensive businesses and responsible for the management of the assets. How much better AM performs in this key task it is expected for the business to have greater performance and maturity.

Organisations seek to value their assets by investing in AM efficiently in order to obtain better returns for their business. As AM process consists of a set of AM key-processes, which are technical and management processes to support and control the assets under management, investing properly in AM means to prioritise the AM Key-processes according to the strategy the business intends to pursue. The identification of which AM key-processes relate to a particular key performance indicator (KPI) of business is a first step in investigating whether the former impacts the latter. This should allow the organisation to invest in the appropriate AM key-process more assertively to improve business.

AM performance and Asset performance (ATTWATER et al., 2014; BITRE, 2017; CHANDIMA RATNAYAKE; MARKESET, 2012; DENNIS et al., 2017; KELLY; HARDY, 2018; MALETIČ et al., 2018; PARIDA, 2012; PARIDA, 2016; PARIDA et al., 2015; SRIMAI, RADFORD; WRIGHT, 2011), as well as AM maturity concepts (CHEMWENO; PINTELON; VAN HORENBEEK, 2013; DENNIS et al., 2017; GODAU; McGEOCH, 2016; MAHMOOD et al., 2015; VOLKER et al., 2013; VOLKER; VAN der LEI; LIGTVOET, 2011), have become hot research topics in the academic and non-academic field in the last ten years, as investment

in AM has increased. Some research discusses the related concepts on review papers (NEL; JOOSTE, 2016; PARIDA et al., 2015), others discuss open issues for the application of AM systems in infrastructure intensive organisations (CHANDIMA RATNAYAKE; MARKESET, 2012; CHEMWENO; PINTELON; VAN HORENBEEK, 2013; DENNIS et al., 2017; ILORI, 2015; KERSLEY; SHARP, 2014; KHALIQ; MAHMOOD; DAS, 2015; KHUNTIA et al., 2016; MEHAIRJAN; FANTANA; SMIT, 2016; PRAGALE; PATEL; BRESDEN, 2018; RODA; MACCHI, 2016; SRINIVASAN; PARLIKAD, 2017; VOLKER; VAN der LEI; LIGTVOET, 2011).

### 5.1.1 AM and Business Performance

The Institute of Asset Management (IAM) (IAM, 2016) affirms that "Organisations are increasingly recognising Asset Management as a discipline that has relevance and significant potential for improving performance". The ISO 55000:2014 standard not only states that AM impacts on business performance, as responsible to realise value from assets, which involves a balancing of costs, risks opportunities and performance benefits, it also lists the expected benefits for business with the implementation and improvement of AM (ISO, 2014a).

The discussion about 'how' the AM contributes to increased business performance is the aim of several references in academic literature articles or Business Reports: focusing on assets (MEHAIRJAN; FANTANA; SMIT, 2016) or on organisation-wide maintenance improvement view (MEHAIRJAN, 2017); proposing AM and business performance frameworks (ATTWATER et al., 2014); offering actual business performance numbers arising from AM actions (DENNIS et al., 2017; WOODHOUSE, 2011); or delving further into the alignment of AM and business strategies (AASHTO, 2011; DWIGHT; El-AKRUTI, 2009), they deliver important insights for the issue, although not yet sufficient to close the question.

This research assumes that AM process and the assets themselves are measured by Asset Performance Indicators - APIs (indicators of the performance of AM process and performance of assets). It is also assumed that AM process is realised by the benefits for business it delivers and by the valuation of assets. As the link between AM process, represented by a set of AM key-processes, and business performance, measured by KPIs, is reliant upon the context of the business, a tangible important connection that evidences the relationship between AM process and business performance is still missing. The main contribution of this research is to offer enablers which are likely relationships between AM key-processes and APIs and KPIs, in asset-intensive organisations. If the relationships are proven, depending on the organisation's need to improve the performance of a specific business KPI, it can make better decisions in

infrastructure directing its investment to those ‘AM key-processes’ that are more probable to deliver the expected results.

To clarify how AM process relates to business performance, through the relation of their performance indicators, a theoretical model was developed: **Asset Management and Business Performance Relationship – AMBP Model**. The AMBP Model offers ‘a relationship map between AM key-processes, APIs and KPIs’, as an enabler for supporting the organisations in infrastructure investment decisions. From these relationships, it shall be possible in future research to discover how the maturity of organisations undertaking AM key-processes impacts the performance of a business, an issue that remains up to date in both the academic and business environments. In other words, knowing ‘how AM process relates to business performance’, the aim of this research, is a fundamental and helpful path to understand other important issues, such as: 'how the AM maturity impacts on business performance' and if high-performance organisations have AM processes at an enhanced degree of maturity.

To establish the relationship between AM process and Business Performance some concepts involving these two main disciplines are necessary to be discussed, including: Asset Management itself, asset value, AM maturity, asset performance indicators (API), business performance and business key performance indicators (KPI). In this section, a brief review of the literature explores them and a discussion about how the industry and research community are treating the theme is given.

AM impacts business performance (DWIGHT; ZHANG; El-AKRUTI, 2013; WOODHOUSE, 2011), but how does AM do it? Maybe the business performance of asset-intensive organisations does depend upon the realisation of value from their assets and the benefits for business that are delivered by the AM process. Concerning the former, AM aims to position the asset towards the optimisation of asset performance against a profile of value requirements (AMADI-ECHENDU et al., 2010; TRINDADE et al., 2019). In terms of the benefits for business, although the relationship between AM and business performance seems natural, there are some important aspects to consider.

ISO 55001 identifies business contextualisation as one of the requirements of the Asset Management System (AMS), which includes understanding the organisation and its context and the needs and expectations of stakeholders (ISO, 2014b). AM objectives need to be aligned to, and consistent with, both the organisational and business strategies (ISO, 2014b; ISO, 2019) so that the AM process implemented can deliver the expected benefits for business.

Several key-processes constitute the AM process (AMC, 2014; GFMAM, 2015) which outputs are asset value and the ‘benefits for business’. Actions taken from one or more of the

AM key-processes may positively or negatively impact the asset's value and therefore the business.

The delivery of 'asset value' to business is measured by the APIs, which establish a metric that is meaningful and applicable through the AM process. APIs can be financial, technical, or non-technical depending upon what is important to the business strategy. Examples are AM finances indicators, operation & maintenance indicators, and AM customer satisfaction, respectively.

Benefits for business represents 'AM process' outputs for the business. They are translated into business performance, measured by KPI when tangible, which purpose is to give transparency of the business performance to the stakeholders. The KPIs also enable preventive and corrective actions, which can lead to different consequences, which are: to ensure the achievement of strategic goals and objectives (CHIRUMALLA et al., 2013; SRIMAI; RADFORD; WRIGHT, 2011), and to provide a broad view of an organisation, as well as to get a competitive advantage over their competitors (ISHAQ BHATTI; AWAN; RAZAQ, 2013; LUSTHAUS et al., 2002).

In a business environment, to ensure that AM actions are aligned to the business strategies and objectives, an appropriate view of the relationship between the APIs and the KPIs must be consistent with the performance management (PM) concept, defined by Parida et al. (2015), as being a "solid foundation for deciding where improvements are most pertinent at any given time". Each organisation must select the APIs and KPIs according to their business strategy and "when the business objectives are changed, the measurement system should be changed accordingly". Having said that, the relationship between the APIs and 'benefits for business' with the KPIs forms a solid performance management framework, which can enable an appropriate investment in AM (BRUNETTO; XERRI; NELSON, 2014; RASTEGARI; SALONEN, 2015).

AM maturity and business performance are increasingly a focus for organisations that have implemented ISO 55000 compliant AM systems. A key reason for this focus is to ensure that the investment in AM systems provides a return for the investment back to the business in terms of better asset performance. As a part of continuous improvement processes, AM maturity is often described as a journey that businesses undertake (GODAU; McGEOCH, 2016; KERSLEY; SHARP, 2014; KHALIQ, MAHMOOD; DAS, 2015; NETWORK RAIL, 2014).

An organisation, that has a high level of maturity in AM, delivers better benefits to the business and adds more value to its assets (KELLY; HARDY, 2018). Therefore, it is imperative that asset-intensive organisations, that aim to be competitive and sustainable, manage their

assets in accordance with the best practices, as well as understand 'how AM maturity reflects on business performance'. An approach to be pursued in addressing this open question is the necessity to first understand how the AM process relates to business performance.

### 5.1.2 AM and its main concepts

This research provides a relationship map that links the AM key-processes with the APIs and the KPIs. It shows how AM process relates to business performance offering insights for future discoveries about how AM Maturity impacts business performance. The AM key-processes, the APIs and the KPIs, and the assumptions of how they relate to each other are the foundation of the AMBP Model described in the following section.

With the intent to ensure that the concepts of AM and its most cited elements in the research are clear, Table 21 shows the differences between them. In the research, when AM is mentioned, it means that a *lato sensu* definition of AM is considered. Unless one of these specific elements is made explicit, AM must be considered. Other examples of elements of AM, then those shown in Table 21, are: AM framework, AM standards, AM System, AM Policies, etc.).

Table 21 - AM and its most cited elements – Concepts

| AM CONCEPTS | |
|---|---|
| AM | A *lato sensu* definition of AM is:<br>AM "involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organisational objectives" (ISO 2014a).<br>AM consists of all the elements as conceptualized bellow among many others (e.g. AM framework, AM standards, AM System.). |
| AM process | AM process refers to a set of the AM key-processes. It is responsible for managing the entire Asset Life Cycle (ALC) and to delivery valued assets and benefits for business |
| AM Key-process | One of the 39 key-processes (subjects) of the Global Forum on Maintenance and Asset Management (GFMAM, 2014). |
| AM actions | AM actions are any action performed in an organisation, in the context of AM, with the aim to solve a problem or to meet a business objective of an organisation. The AM actions relate to one or more AM key-processes. |
| AM performance | Refers to the performance of the AM process. It is measured by APIs, as: reduction in maintenance days, reduction in spares, number of incidents, number of HSE complaints, among others. |
| Asset performance | Refers to the performance of the asset, which is 'the effect of maintenance on assets'. It is measured by APIs, as: number of equipment failures, MTBF, MTTR, downtime, availability, energy consumption, overall equipment effectiveness, among others |

Source: Lima, McMahon and Costa (2020)

It is important to highlight that the purpose of this research is not about establishing a hierarchical relationship of the APIs and KPIs but about how to identify relationships that can be evidenced by the case studies in AM, without addressing concerns about the hierarchy or ranking between the indicators.

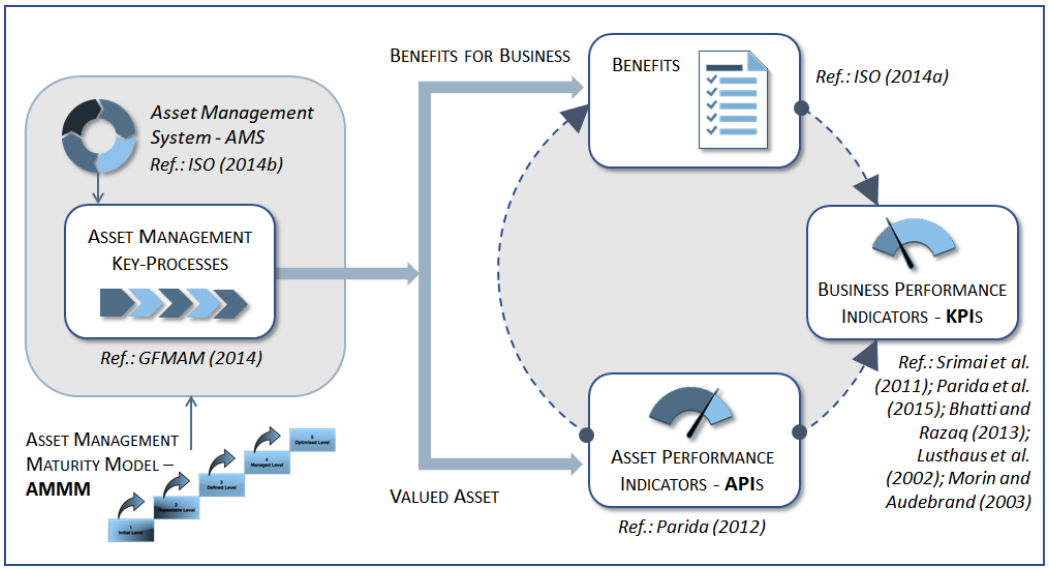
## 5.2 MODEL STRUCTURE

To understand how the AM process relates to business performance, which is the objective of this research, it is suggested the AMBP Model, which is a theoretical model designed in two parts: the AMBP Structure and the AMBP Methodology, described in the next sections.

### 5.2.1 AMBP Structure

The AMBP Structure is shown in Figure 22 and its main elements, Asset Management Maturity Model, AM key-processes, Benefits for business, Asset performance indicators (APIs) and Business Performance indicators (KPIs) are described hereunder.

Figure 22 - AMBP Structure




Source: Lima, McMahon and Costa (2020)

#### 5.2.1.1 Asset Management Maturity Model

The AM key-processes and the asset management system (AMS) (ISO, 2014b) can be assessed by an Asset Management Maturity Model (AMMM). The result is a measure of the organisation's AM maturity level to provide a pathway for improvement in the management of

the asset to achieve business outcomes. In other words, it is a measure of the organisational understanding of, and application of the set of AM key-processes or how compliant the AM key-processes are with the best practices. While the AMMM is linked to the AM Structure, it is not the focus of this research.

#### 5.2.1.2 AM key-processes

As shown in the AMBP Structure, AM process is represented by a set of key-processes that are responsible for managing the entire Asset Life Cycle (ALC), which includes specifying, acquiring, implementing, operating, maintaining, retiring and disposal of assets. To justify the reference to the AM key-processes to be used in the AMBP Model, the 39 key-process of the Global Forum on Maintenance and Asset Management (GFMAM) (GFMAM, 2014) were compared with the Asset Management Council's 30 key-processes (AMC, 2014) and Mahmood's 28 key-processes (MAHMOOD et al., 2015). The latter is derived from the systematic review of the extensive literature on AM.

The comparison has shown that all the key-processes of the two compared references can be incorporated into GFMAM, although some assumptions about the similarity of the key-processes must be made. For example: 'Stakeholder management' and 'Interagency collaboration' in Mahmood et al. (2015) can be represented by 'Stakeholder engagement' in GFMAM (2014); 'Organisational roles' in AMC (2014) can be represented by 'Organisational structure' and 'Organisational culture' in GFMAM (2014). Therefore, as GFMAM covers the AM key-processes in a larger view, it was chosen to be the reference for the AM key-processes, as shown in Table 22.

#### 5.2.1.3 Asset Performance Indicators (API)

Asset performance is intrinsically part of business processes and is required to ensure business performance. Increasingly, AM is being regarded as a competitive advantage by companies who are looking at maximizing the return on assets under management (RISA; LIYANAGE, 2015; TOO, 2008; TOO; TOO, 2010). The measurement of the asset performance is realised through the indicators chosen by the organisation, depending on its objectives, and a good choice of the APIs can be a powerful tool to focus on opportunities for improvement.

The definition of API used in the AMBP Model was adapted from the concept of Maintenance Performance Indicators (MPI) by Parida et al. (2015). It is assumed that API is an indicator to measure and understand both 'the value created by the assets' and 'the AM performance'. The analysis of the results obtained through the APIs helps to re-evaluate and

revise the AM policies; to justify investments in new trends and techniques; and to revise resource allocations.

Table 22 - AM key-processes

| KEY-PROCESSES | | |
|---|---|---|
| AM Strategy & Planning | 1 | Asset Management Policy |
| | 2 | Asset Management Strategy & Objectives |
| | 3 | Demand Analysis |
| | 4 | Strategic Planning |
| | 5 | Asset Management Planning |
| AM Decision-making | 6 | Capital Investment Decision-Making |
| | 7 | Operations & Maintenance Decision-Making |
| | 8 | Lifecycle Value Realisation |
| | 9 | Resourcing Strategy |
| | 10 | Shutdown & Outage Strategy |
| Life-Cycle Delivery activities | 11 | Technical Standards & Legislation |
| | 12 | Asset Creation & Acquisition |
| | 13 | Systems Engineering |
| | 14 | Configuration Management |
| | 15 | Maintenance Delivery |
| | 16 | Reliability Engineering |
| | 17 | Asset Operations |
| | 18 | Resource Management |
| | 19 | Shutdown & Outage Management |
| | 20 | Fault & Incident Response |
| | 21 | Asset Decommissioning and Disposal |
| Asset Knowledge enablers | 22 | Asset Information Strategy |
| | 23 | Asset Information Standards |
| | 24 | Asset Information Systems |
| | 25 | Data & Information Management |
| Organisation & people enablers | 26 | Procurement & Supply Chain Management |
| | 27 | Asset Management Leadership |
| | 28 | Organisational Structure |
| | 29 | Organisational Culture |
| | 30 | Competence Management |
| Review and continuous improvement | 31 | Risk Assessment and Management |
| | 32 | Contingency Planning & Resilience Analysis |
| | 33 | Sustainable Development |
| | 34 | Management of Change |
| | 35 | Assets Performance & Health Monitoring |
| | 36 | Asset Management System Monitoring |
| | 37 | Management Review, Audit & Assurance |
| | 38 | Asset Costing & Valuation |
| | 39 | Stakeholder Engagement |

Source: GFMAM (2014)

The reference used for the APIs in the AMBP Model is an adaptation of the 'Multi-criteria hierarchical Maintenance Performance Assessment (MPA) framework for Engineering Asset', by Parida (2012). The author proposed 7 criteria and successfully tested each of the criteria out for different sectors of the economy including railway, heavy truck and energy.

In its turn, the MPA framework is an adaptation of the Maintenance Performance Measurement (MPM) framework by Parida and Chattopadhyay (2007), which embodies the concepts of four perspectives of Balanced Score Card (BSC), making it a balanced and holistic framework from the organisational point of view (PARIDA, 2008). The criteria and the equivalent API identification for the AMBP Model are internal processes (API02), financial (API03), customer (API06) and learning and growth (API05). Besides these four perspectives other three were added to compose the Framework: the engineering asset criteria (API01), employee satisfaction (API07) and health, safety and environment (API04).

Table 23 - Asset Performance Indicators

| ASSET PERFORMANCE INDICATORS | | INSTANTIATED CONCEPTS TO THE AMBP MODEL |
|---|---|---|
| API01 | Asset-related indicators | Aspects related to the asset itself. |
| API02 | O&M indicators | Tailored for the asset's operation and maintenance **process** perspective. Specifically refers to management activities. |
| API03 | AM financial indicators | Related to the financial aspects of the entire asset life cycle (ALC). The indicators include costs related to the purchase of equipment and facilities aimed at improving a product, service or the company itself (CAPEX), as well as operating expenses and expenditures and investment in equipment maintenance (OPEX). |
| API04 | HSE indicators | Embody all health, safety and environment aspects related to asset management, including risk management process instantiated to AM. |
| API05 | Learning & Growth | Refers to the actions of learning with the AM process aiming at the development of AM and its position in line with the organisational strategy. |
| API06 | Customer satisfaction | Related to the AM process' customers. They may exist internally and externally to the organisation, depending on whom the products or services generated in the AM process are intended. |
| API07 | Employee satisfaction | Related to the satisfaction of the AM process' employees. Professionals that work in various aspects of the AM process, from the development, procurement, engineering, finances, operation and maintenance and asset disposal. They can be part of the organisation's employees. |

Source: Adapted from Parida (2012) apud Lima, McMahon and Costa (2020)

Both, the MPA framework and the MPM framework, focus on the asset maintenance process, undoubtedly an important aspect of the asset's life cycle, and considered the most critical role although it is not the only one (ATTWATER et al., 2014; PARIDA, 2016). Despite this detail, the AMBP Model proposes an adaptation of the MPA framework considering the

entire asset life cycle for the 7 perspectives. These perspectives and their related concepts instantiated to AMBP Model's APIs are shown in Table 23.

#### 5.2.1.4 Benefits for business

Obtaining value from assets in achieving the organisational objectives is the primary function of AM. As the value depends on these objectives and on the stakeholder's expectations, there are several potential benefits to be obtained for the business performance.

ISO 55000:2014 (ISO, 2014a) lists 9 benefits for business (B1 – B9) as shown in Table 24.

Table 24 - Benefits for business

| BENEFITS FOR BUSINESS | |
|---|---|
| B1 | Improved financial performance |
| B2 | Informed asset investment decisions |
| B3 | Managed risk |
| B4 | Improved services and outputs |
| B5 | Demonstrated social responsibility |
| B6 | Demonstrated compliance |
| B7 | Enhanced reputation |
| B8 | Improved organisational sustainability |
| B9 | Improved efficiency and effectiveness |
| B10 | Improved employee performance |
| B11 | Improved engagement |
| B12 | Improved innovation |

Source: Adapted from ISO (2014a) apud Lima, McMahon and Costa (2020)

Three additional benefits (B10 – B12) were identified with the application of the AMBP Model and are also shown in Table 24. 'Improved employee performance' (B10) is expressed as meeting employee performance targets (CHANDIMA RATNAYAKE; MARKESET, 2012), through improved employee competence, awareness and confidence, in the understanding of AM and the benefits it brings for business. 'Improved engagement' (B11) represents the effectiveness of interaction and communication with stakeholders and employees (ZUASHKIANI; RAHMANDAD; JARDINE, 2011), as well as the provision of a collaborative environment between all levels of management. This shall include all areas required for the achievement of strategic objectives in a systemic view. 'Improved innovation' (B12) denotes successful exploitation of new ideas as crucial to a business being able to survive in changing

conditions; innovation of asset processes to meet changes in business environment more effectively without disrupting existing asset operations (HAMMER, 2004); and improving the business with new technologies, models, processes and methods, related to assets and AM.

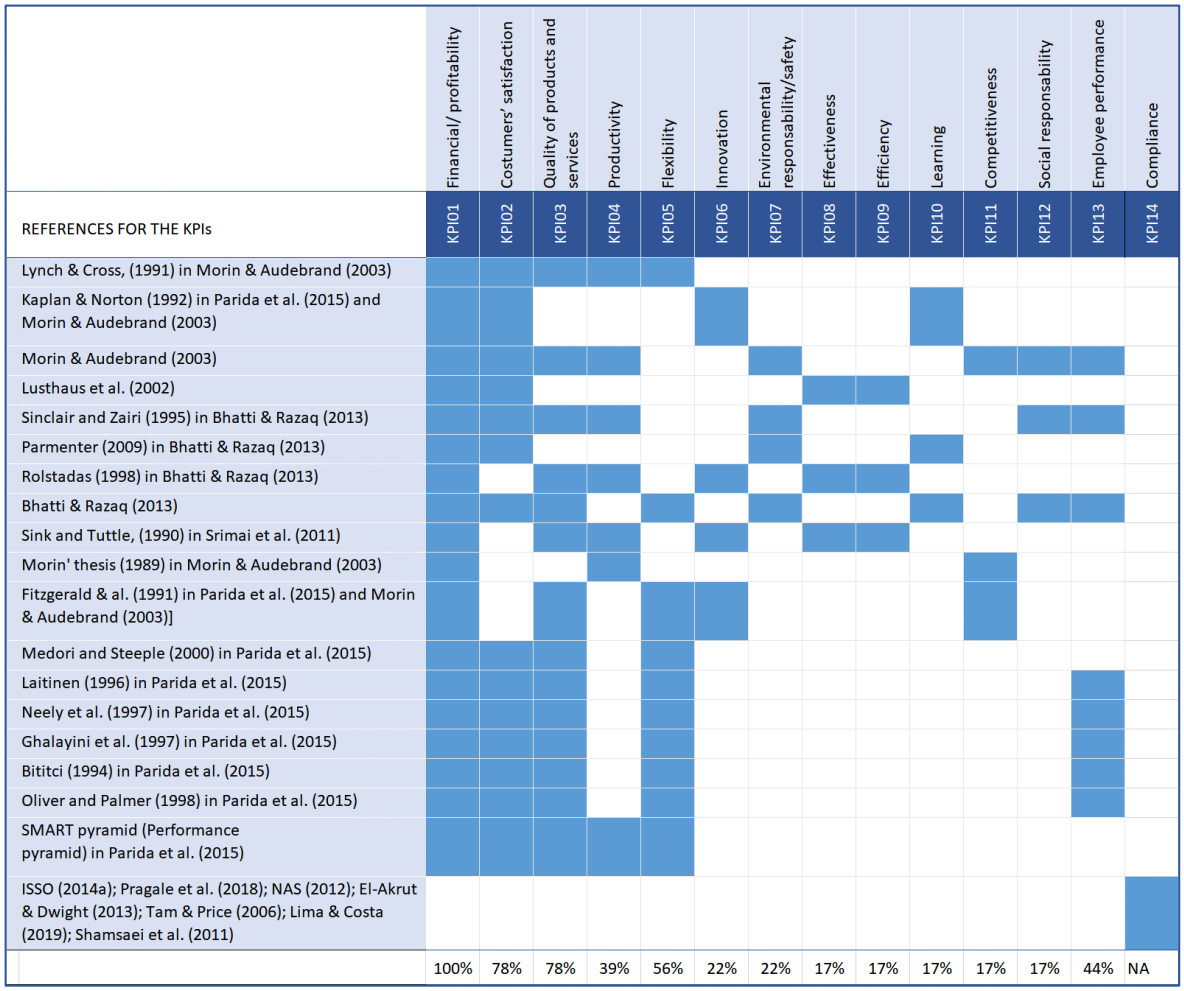
#### 5.2.1.5 Business Performance Indicators (KPI)

Business performance management is a key part of reviewing the overall business and determining how the business can better reach its goals. To provide a measure of the business performance, metrics (KPIs) are selected which are aligned to the organisation's strategic objectives. KPIs are a fundamental part of any business' performance management as they enable tracking and better managing the level of performance and success of the strategies. They vary according to the competitive environment, business life cycle, strategies and many other factors.

For the AMBP Model, as the aim is not to instantiate the metrics to any particular company or sector of the economy, the 13 business KPIs, shown in Figure 23, were selected as they were the most frequently cited in the comparison of 18 models, collected from papers of organisation performance (ISHAQ BHATTI; AWAN; RAZAQ, 2013; LUSTHAUS et al, 2002; MORIN; AUDEBRAND, 2003; PARIDA et al, 2015; SRIMAI; RADFORD; WRIGHT, 2011).

The aditional KPI14 - Compliance was identified with the application of the AMBP Model. Although the compliance indicator was not contemplated by the authors of the analysed business KPI models, it was considered to be the 14$^{th}$ KPI in AMBP Model because of the following reasons: first, AM compliance is considered to be a key part of the business processes by infrastructure companies (El-AKRUTI, K.; DWIGHT, 2013; PRAGALE; PATEL; BRESDEN, 2018); second, in various scenarios investment may not occur unless AM compliance is included in the scope for the lifecycle of the asset (TAM; PRICE, 2006); third, it is one of the nine general areas in which the AMS may deliver benefits to an organisation (ISO, 2014a); and last, because compliance is also a key aspect evidenced in most of the case studies, as discussed later in this study. Furthermore, there are many reasons for compliance to business: Requirement under legislation (safety, imposition of the granting public authority) (LIMA; COSTA, 2019; SHAMSAEI; AMYOT; POURSHAHID, 2011) and other requirements, such as: Government requirement for allocation of funds from the treasury to ensure the money is spent wisely; Business requirement (e.g., managing assets on behalf of asset owner and the owner requires an AM plan) (CAVKA; STAUB-FRENCH; POIRIER, 2017). Figure 23 shows the 14 KPIs and their respective references.

Figure 23 - Business KPIs




Source: Lima, McMahon and Costa (2020

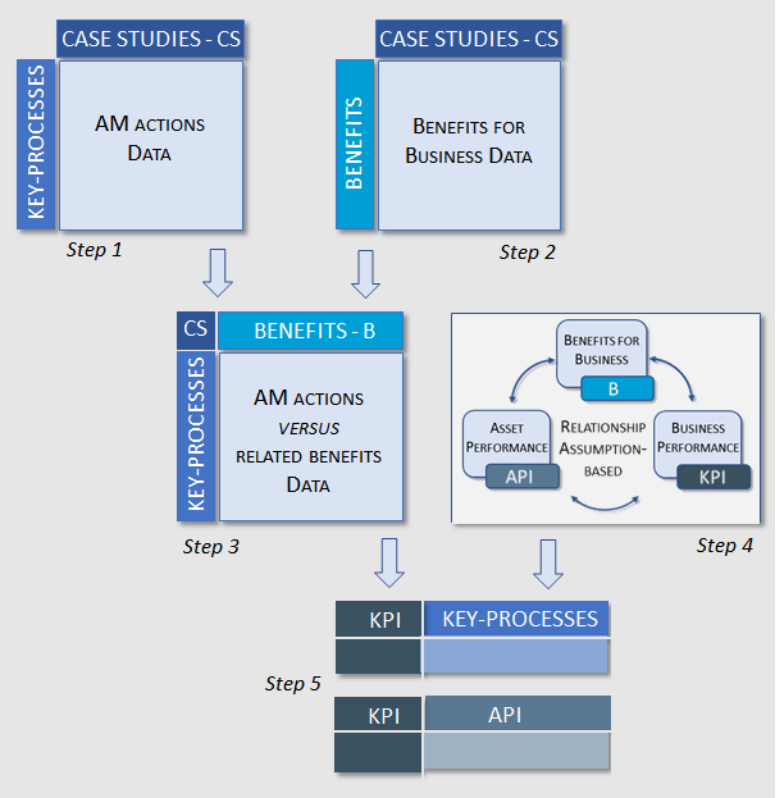
### 5.2.2 AMBP Methodology

The objective of the AMBP Methodology is to identify links between AM process and business performance. The input data for the AMBP Methodology comprises (a) evidence of AM actions, performed with the aim to solve a problem or to meet a business objective in organisations of different sectors of the economy, and (b) evidence of benefits for business that are a consequence of the AM actions. The input data are collected from Case Studies published in the academic literature or specialized sites. There are five steps in the AMBP methodology, as illustrated in Figure 24 and depicted below.

**Step 1:** Each case study is analysed in terms of four dimensions or elements: context, problem, demand and implemented AM actions related to AM key-processes. The result is the identification of the AM key-processes related to the AM action, and the improvement action itself. For a more accurate assessment, one must consider the context of the organisation as fundamental in understanding the AM system focus and selection of key-processes.

**Step 2:** For each case study, the benefits for business, based on interpretation of the achieved or expected results, which were a consequence of the AM actions identified in Step 1, are pointed out. In this stage, it is not yet possible to associate the benefits for business with a specific AM key-process. This is achieved in Step 3.

Figure 24 - AMBP Methodology

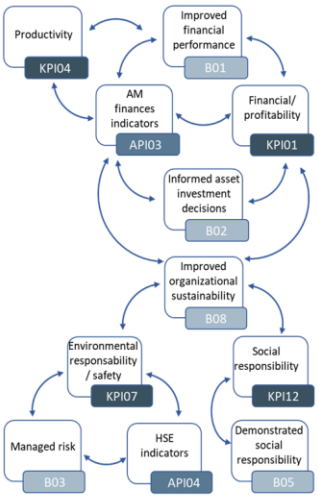
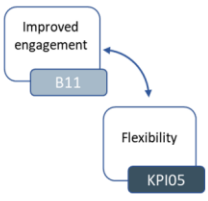
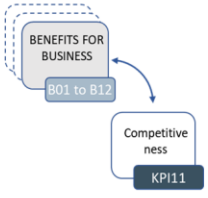



Source: Lima, McMahon and Costa (2020)

**Step 3:** Based on the results of Steps 1 and 2, an interpretative analysis for each case study is developed. The objective is to highlight where AM key-processes are performed by an AM action, as well as the respective 'benefit for business' achieved as a result of this AM action.

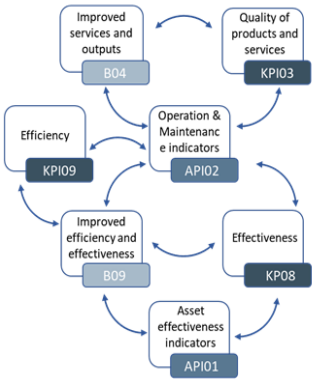
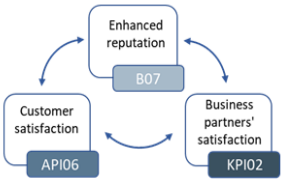
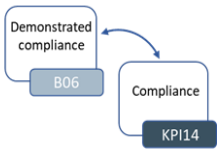
**Step 4:** For the relationship between the 'benefits for business', the APIs and the KPIs, some assumptions are made to explain how these relationships occur, as illustrated and detailed in Figures 25 and 26. Understanding how these three elements relate to each other is essential to the answer to the research question: 'How does AM process relate to business performance?'. As discussed by Attwater et al. (2014), good AM reflects in good asset performance, measured by APIs, which in turn reflects in a good performance for business, measured by KPIs.

Figure 25 - Premises for the relationship between Benefits for business, API and KPI (Part 1)

| RELATIONSHIP | ASSUMPTIONS | ELEMENTS | ELEMENT MEANING |
|---|---|---|---|
|  | Best practice in AM promotes the improvement of the organisation's financial performance (B01) and informed asset investment decisions (B02). Consequently, better AM financial indicators (API03) reflects on business profitability (KPI01). Simultaneously, improved financial performance (B01) promotes the AM financial indicators (API03) resulting in better productivity (KPI04). Best practice in AM related to sustainability leads to the improvement of the organisational sustainability (B08). This benefit results in the improvement of the business indicators 'Environmental responsibility and safety' (KPI07), 'Social responsibility' (KPI12) and 'Financial Profitability' (KPI01). Best practice in AM related to risk result in improved management risk (B03) and better HSE indicators (API04). Both promote business indicator 'Environmental responsibility and safety' (KPI07). Best practice in AM related to social issues demonstrates social responsibility (B05), that can be measured by the business indicator 'Social responsibility' (KPI12). | Improved financial performance (B01) | "Improving the return on investments and reducing costs can be achieved, while preserving asset value and without sacrificing the short or long-term realization of organizational objectives" (ISO, 2014a). |
| | | Informed asset investment decisions (B02) | "Enabling the organization to improve its decision making and effectively balance costs, risks, opportunities and performance" (ISO, 2014a). |
| | | Managed risk (B03) | "Reducing financial losses, improving health and safety, good will and reputation, minimizing environmental and social impact, can result in reduced liabilities such as insurance premiums, fines and penalties (ISO, 2014a). |
| | | Demonstrated social responsibility (B05) | "Improving the organization's ability to, for example, reduce emissions, conserve resources and adapt to climate change, enables it to demonstrate socially responsible and ethical business practices and stewardship" (ISO, 2014a). |
| | | Improved organisational sustainability (B08) | "Effectively managing short and long-term effects, expenditures and performance, can improve the sustainability of operations and the organization" (ISO, 2014a). |
| | | AM finances indicator (API03) | Accurate reporting of expenditure and budgetary requirements, all asset expenditure captured through AM system (Ambec et al., 2013). |
| | | HSE indicators (API04) | Health, safety and environmental issues, including "accidents, incidents, environmental problems, breach of securities, injuries, asset loss, and fatalities" (Parida & Chattopadhyay, 2007). |
| | | Financial/profitability business (KPI01). | Meeting financial forecasts for returns on assets including expenditure forecasts and business earnings. "The ability of an organization to raise the funds required to meet its functional requirements in the short, medium and long term" (Lusthaus et al., 2002). |
| | | Productivity (KPI04). | "Productivity is efficiency in production: how much output is obtained from a given set of inputs ….. Single-factor productivity measures reflect units of output produced per unit of a particular input" (Syverson, 2011). |
| | | Environmental responsibility/ safety (KPI07) | Meeting environmental targets, including reducing emissions (Energex, 2014). |
| | | Social responsibility (KPI12) | Social responsibility targets are met through stakeholder and community consultation undertaken with integrity and good will (Maletič, 2018). |
|  | Best practice related to the satisfaction of the employees in the AM process (API07) lead to the improvement of the employee performance (B10) and an improvement of the employee performance indicator (KPI13) is expected. | Improved employee performance (B10) | Meeting employee performance targets (Chandima Ratnayake and Markeset, 2012). |
| | | Employee satisfaction (API07) | Improved survey satisfaction responses from employees for treating employees with respect, providing regular employee recognition. Employee satisfaction with positive management within a success framework of goals (Tessema et al., 2013). |
| | | Employee performance (KPI13) | Measurement of attractiveness of compensation, friendly leadership, balance between work-life conflicts and healthy work environment (Tessema et al., 2013; Luthans, 2016). |
|  | Best practice in AM result in demonstration of improved engagement (B11) which can lead to business flexibility (KPI05), through the support of all those engaged. | Improved engagement (B11) | Measurement of effectiveness of interaction and communication with stakeholders and employees. Stakeholder requirements are collected and outcomes are discussed with stakeholders. Decision processes are communicated with stakeholders (Zuashkiani, 2011). |
| | | Flexibility (KPI05) | Measurement of adaptability due to competition or to changes in business conditions such as demand, being able to ramp up output when required and reduce output when demand falls (Harris and Carapiet, 2006; HFM,2013) |
|  | It is reasonable to assume that all the benefits for business from the best practice in asset management, as a finalist process, converge to increasing business competitiveness. | Competitiveness (KPI11) | "The competitiveness of the economy at the macro level is associated with the duration of the cycle of reproduction of the main productive assets and, accordingly, the jobs, productive forces of society and determined by the overall economic efficiency of investment" (Hooke, 2017). |

Source: Lima, McMahon and Costa (2020)

Figure 26 - Premises for the relationship between Benefits for business, API and KPI (Part 2)

| RELATIONSHIP | ASSUMPTIONS | ELEMENTS | ELEMENT MEANING |
|---|---|---|---|
|  | Best practice in AM results in good operation and maintenance indicators (API02) which can lead to the benefits for business: 'Improved services, -products and outputs' (B04) and 'Improved efficiency and effectiveness' (B09). Other consequences are an improvement of Efficiency (KPI09), Quality of products and services (KPI03) and Effectiveness (KPI08) benefiting the business. The latter is formulated from the 'Asset effectiveness indicator' (AP01) as well. | Improved services and outputs (B04) | "Assuring the performance of assets can lead to improved services or products that consistently meet or exceed the expectations of customers and stakeholders" (ISO, 2014a). |
| | | Improved efficiency and effectiveness (B09) | Meeting continuous improvement for business efficiency and effectiveness, reviewing and improving processes, procedures and asset performance (Ilori, 2015). |
| | | Asset-related indicators (API01) | Developing asset indicators to more effectively measure asset performance. Collecting data related to asset indicators for decision making regarding asset condition (Parida, 2012). |
| | | Operation & Maintenance indicators (API02) | Accurate report with information on availability, reliability, preventive maintenance, corrective maintenance, systems shutdown, outage and restart and associated costs (Parida, 2012). |
| | | Quality of products and services (KPI03) | Meeting quality requirements, reduction in customer returns, reduction in customer service complaints (El-Akruti and Dwight, 2013). |
| | | Effectiveness (KPI08) | Effectiveness is a central term "used in assessing and measuring the performance of organisations"…. and also "apply to business arrangements such as strategic alliances, joint ventures, sourcing and outsourcing agréments" (Mouzas, 2006). |
| | | Efficiency (KPI09) | Improved utilisation of resources to provide desired outputs (Ma et al., 2014). |
|  | Best practice in AM leads to 'Customer satisfaction' (API06) and 'Enhanced reputation' (B07) which result in the improvement of the 'Business partners' satisfaction' (KPI02). | Enhanced reputation (B07) | "Through improved customer satisfaction, stakeholder awareness and confidence" (ISO, 2014a). |
| | | AM Customer Satisfaction (API06) | Measure of customer satisfaction related to their expected value over the asset (BITRE, 2017). |
| | | Business partners' satisfaction (KPI02) | Measure of business partners' satisfaction related to their expected value over the asset (BITRE, 2017). |
|  | Best practice approaches in AM lead to the benefit of business 'Demonstrated compliance' (B06) which result in the improvement of the related KPI (KPI14) | Demonstrated compliance (B06) | "Transparently conforming with legal, statutory and regulatory requirements, as well as adhering to asset management standards, policies and processes, can enable demonstration of compliance" (ISO, 2014a). |
| | | Compliance (KPI14) | To be aligned with the internal and external policies and guidelines established for a business, that is, to act in accordance with the rules and determinations of all regulatory bodies in the ethical, fiscal, accounting, environmental, legal, social security and labour (El-Akruti and Dwight, 2013). |
|  | Best practice in AM leads to AM learning and growth (API05) which contributes to business learning indicator (KPI10) and foster the improvement of business innovation (B12). As a consequence, it's expected better business innovation indicator (KPI06). | Improved innovation (B12) | Successful exploitation of new ideas is crucial to a business being able to survive in changing conditions. Innovation of asset processes to meet changes in business environment more effectively without disrupting existing asset operations (Hammer, 2004). |
| | | Learning & Growth (API05) | Measuring how well the organisation is improving and growth in knowledge of asset management processes (Dwight and El-Akruti, 2009). |
| | | Innovation (KPI06) | Meeting innovation targets in improvements in business processes and development of new products and services. Improving or replacing business processes to increase efficiency and productivity (Hammer, 2004). |
| | | Learning (KPI12) | Learning is a necessity for organizations to remain adaptive and competitive in today's ever-changing business environment (Edmondson, 2008). |

Source: Lima, McMahon and Costa (2020)

As can be seen in Figure 25 and 26, some relationships are easy to identify because they have an explicit connection regarding their purpose as the names suggest, such as: 'KPI01 - Financial/ profitability' x 'API03 – AM finances indicators' x 'B01 - Improved financial performance'; 'KPI12 - Social responsibility' x 'B05 - Demonstrated social responsibility'. Others, however, need a more theoretical explanation and grounding, such as: 'KPI11 –

Competitiveness' x 'Benefits for business' and 'KPI05 – Flexibility' x 'B11- Improved engagement'.

The business indicator 'KPI11 – Competitiveness' is difficult to be associated with a specific "benefit for business" because it depends on many internal and external aspects of a business. Examples of internal aspects are: improved financial performance; informed asset investment decisions; managed risk; improved efficiency and effectiveness; improved engagement and improved innovation. All of these internal aspects are cited as a 'benefit for business' that results from the implementation of AM (ISO, 2014a).

In the macroeconomic context, competitiveness is associated with a set of factors such as the growth of social productivity of labour; increase of economic efficiency of production; increase in the standard of living of the population; sustainable development (HOOKE, 2017); well-designed regulations, as established by the Porter Hypothesis (AMBEC et al, 2013); and the status of the competitors, among others. As the organisational performance context reflect the macroeconomic factors, the indicator 'KPI11-Competitiveness' was proposed to be linked with all the benefits for business, as can be seen in Figure 25.

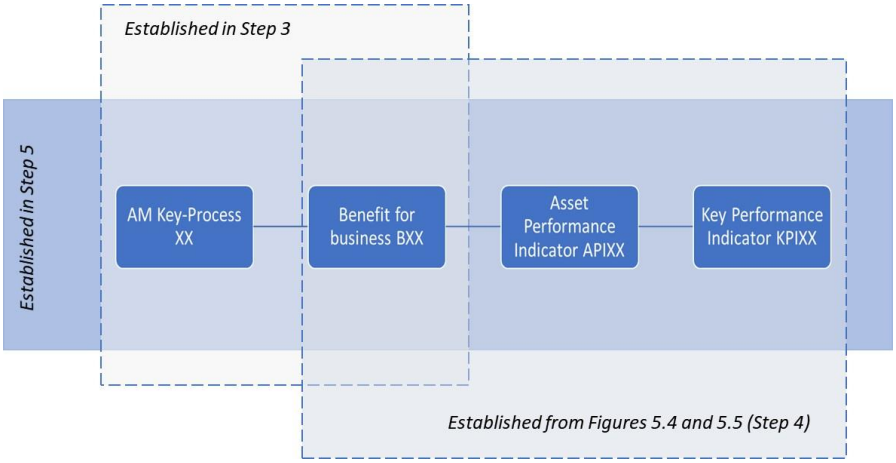
In regard to 'KPI05 – Flexibility', the more engaged and aligned stakeholders are with the organisation's strategic objectives, it's expected that the greater the readiness or flexibility of the organisation to adapt to new challenges. Flexibility is a key attribute for organisations in being able to adapt to different scenarios or changes in the context of business operations. This flexibility requires a closer engagement with stakeholders to ensure the communications are effective and aligned with organisational objectives.

**Step 5**: In considering the results obtained from Steps 3 and 4 as an input, the relationships among AM key-processes with benefits for business, APIs and KPIs are obtained. For each key-process that has one or more identified AM actions, there is one or more associated benefits, which in turn are associated with an API and/or a KPI.

Note that the link between the AM key-processes with the 'benefits for business' is the result of an interpretative analysis by the authors (Step 3), while the link between the benefits for business with APIs and KPIs (Step 4) is established in Figures 25 and 26, which was based on the literature. From these two links, it's possible to establish the relationship between AM key-processes with benefits, APIs and KPIs. Figure 27 shows how Steps 3, 4 and 5 of the Methodology relate to each other.

An application of the AMBP Model, based on 13 case studies of organisations from various sectors of the economy, including energy, health, local council services, transport, agribusiness and mining, is depicted next.

Figure 27 - Boundaries of Steps 3, 4 and 5 of the Methodology




Source: Lima, McMahon and Costa (2020)

## 5.3 APPLICATION OF THE AMBP MODEL

This section aims to show how the AMBP Model is applied in practice. All steps are depicted in detail, including the methodology to choose the case studies for evidencing the input data. The results show evidence of relationships between AM key-process and benefits for business, APIs and KPIs.

**Case Studies:** The AMBP Model was applied to establish the relationship between AM process and business performance, using the data of 13 AM case studies, as shown in Tables 25, 26 and 27. The case studies describe AM actions and improvements, in response to the need faced by an organisation to solve a problem related to the management of its assets. They also describe the respective results achieved or desired.

The methodology for choosing the case studies was based on meeting the requirement for intensive infrastructure under management, within different industrial sectors. This was important to ensure a wide spectrum of different types of assets. Besides that, the organisations identified challenges in the asset under management.

A qualitative analysis of each of the case studies was conducted. In this analysis, the data from each of the case studies were examined individually by each of the authors. In some of the case studies, the AM actions, benefits, and linkages between them were not always easy to identify, so, the only evidence that had convergent interpretations were considered.

**Step 1:** For the identification of the AM actions, which are related to AM key-processes, an interpretative analysis of the case studies was carried out. The interpretive analysis in this research was justified as the connection of the AM action and the AM key-process was not always evident, requiring interpretation.

Table 25 - Details of the AM Case Studies (CS01 – CS04)

| ID | CS01 | CS02 | CS03 | CS04 |
|---|---|---|---|---|
| TITLE | Asset integrity assessment | AM audit: strategy development and implementation | Asset management training | ISO 55001 gap assessment |
| ORGANISATION | Energy Resources Australia (ERA) | CBH Group | Hydro Tasmania | Hydro Tasmania |
| BUSINESS | Uranium Mine | Agribusiness | Hydroelectric power and renewable energy | Hydroelectric power and renewable energy |
| PROFILE | ERA is “Australia’s longest continually operating uranium producer”. It “operates the Ranger Uranium Mine in Australia’s Northern Territory”. | “CBH is a large agribusiness which owns and manages one of the most sophisticated grain storage and handling networks in the world”. | It is the largest water manager in Australia. It is the “Australia’s leading producer of renewable energy, with over 100 years of experience producing hydroelectric power”. | It is “the largest water manager in Australia”. It is the “Australia’s leading producer of renewable energy, with over 100 years of experience producing hydroelectric power”. |
| PROBLEM | “ERA experienced a catastrophic failure of one of its leach tanks at the Ranger Mine”. | CBH “recognised the importance of Asset Management to the long term efficiency of the business”. In spite of this, it needs to improve its AM processes faced to the criticality of its large portfolio. | Hydro Tasmania's “asset base is ageing, creating challenges for the organisation … to ensure production meets demand and reduce asset risks” and to ensure that all key stakeholders were aware of this role in effective AM. | Hydro Tasmania’s “asset base is ageing, creating challenges for the organisation” from “reducing performance, increasing maintenance burdens, increasing risk and the resulting repair/replace decision making” |
| AM RELATED ACTION | Conduction of a risk-based review “to identify the actions for restart of the plant and be assured that there were no significant systemic risks that required their attention”. | “Benchmark asset management at CBH against the requirements of PAS 55”; “Develop a roadmap of actions to strengthen CBH’s asset management practices”; “Aid CBH to implement the required actions and monitor success”. | Competence Management: A two-day course “Implementing an ISO 55000 Compliant Asset Management System” for Hydro Tasmania's staff. | Assessment of Hydro Tasmania's maturity across the ISO 55001 to identify opportunities that would allow it “to achieve an assessment of Competent required for full compliance and future certification”. |
| SOURCE | Assetivity (2016a) | Assetivity (2015a) | Assetivity (2016b) | Assetivity (2016c) |

Table 26 - Details of the AM Case Studies (CS05 – CS08)

| ID | CS05 | CS06 | CS07 | CS08 |
|---|---|---|---|---|
| TITLE | Maintenance & operating cost estimation development | Maintenance & reliability improvement program | Am accountability framework (amaf) gap assessment | Operational readiness support |
| ORGANISATION | An Australian iron ore company | PanAust | Royal Women's Hospital | Santos Ltd. |
| BUSINESS | Iron ore mine | Copper and gold producer | Women and newborns' health | Oil and gas producer |
| PROFILE | "An Australian iron ore company who controls the rights to a large tenement portfolio across the Pilbara region". | "PanAust is a leading copper and gold producer in Southeast Asia and has a portfolio of pre-development projects in Laos, Chile and Papua New Guinea". | "The Royal Women's Hospital is Australia's largest specialist hospital dedicated to improving the health of all women and care of newborns" | "Santos is one of the leading independent oil and gas producers in the Asia-Pacific region, supplying the energy needs of homes, businesses, and major industries across Australia and Asia." |
| PROBLEM | The company needed assistance to estimate the O&M cost "for the operation of the central processing facility and power generation plant" for a mine and market pre-feasibility study of the one of their Iron Ore Projects | "To support its growth objectives, while maintaining consistency and discipline across its operations, PanAust sought to establish a consistent approach to asset maintenance and reliability management across all their operations". | The AM Accountability Framework has additional requirements to ISO 55001. As a Public Sector agency, the Royal "sought to determine its level of compliance with the AMAF requirements". | "Santos identified the need to develop effective maintenance and integrity management plans to assure the reliability and integrity of the new facilities". It needs undertaking "operational readiness activities for all the GLNG gas extraction, transmission, and processing supply chain". |
| AM RELATED ACTION | The estimation of "the maintenance and operating cost for the operation of the central processing facility and power generation plant". | "An external maintenance audit was performed…. The findings enabled PanAust to prioritise and scope the work for the remainder of the improvement project". | An assessment of the compliance with the mandatory requirements of the AM Accountability Framework to indicate "their current level of maturity towards achieving full compliance." | Developing and implementing AM processes to help Santos "to achieve high levels of reliability right from the commencement of operations". |
| SOURCE | Assetivity (2015b) | Assetivity (2015c) | Assetivity (2018) | Assetivity (2016d) |

Table 27 - Details of the AM Case Studies (CS09 – CS13)

| ID | CS09 | CS10 | CS11 | CS12 | CS13 |
|---|---|---|---|---|---|
| TITLE | Conductor strategy review | Keep it simple, sensible asset management | Asset management in the city of Fredericton | Why asset management should be a corporate function? | Asset management beyond roads |
| ORGANISATION | Western Power | City of Charles Sturt, Adelaide, South Australia | City of Fredericton, New Brunswick, Canada | City of Brimbank, Victoria, Australia | Campbelltown City Council (NSW) |
| BUSINESS | Electricity network | Local Government | Local Government | Local Government | Local Government |
| PROFILE | WP "is responsible for building, maintaining and operating the electricity network …, covering an area of 261000 square kilometres". | "The City of Charles Sturt is a fully developed urban city …". "The City provides some 30 plus services to its community and these services are supported by vital community infrastructure". | Fredericton is the capital city of New Brunswick with a population of "currently 57,000 and the population in the Greater Fredericton Region of approximately 100,000". | "Brimbank City Council services over 180,000 residents and is the third largest metropolitan Council in Melbourne". | "Campbelltown City Council (NSW) is responsible for the management of its assets stock with a replacement cost of approximately $950 million". |
| PROBLEM | The absence of adequate driver condition information leads to AM decisions that have the potential to result in less efficient investment. | Government need to plan strategically and moving towards 'Strategic AM' to be assisted in "sustaining, improving and rationalising the services that it provides today" to ensure the same for future, or improved, services. | "While the staff … recognized that the City had an infrastructure deficit" and it would take a concerted effort to reduce it, there was difficult to articulate the extent of the deficit" because there was no formal AM system in place". | The Council is "confronted by numerous legacy problems and issues associated with the quality and type of its asset base and its flexibility in supporting future service needs". | "Council has identified a need to develop Long-term Strategic Financial Plans for the effective management of assets" focusing not only on Roads but "extended for the effective management of other assets. |
| AM RELATED ACTION | AM knowledge management; Change management to improve awareness of specific failure; Competence Management to improve the understanding of the current Program. | Developing and implementing Strategic Asset Management (SAM). Discuss methods by which SAM "can be made simple, sensible and practical". | A review of "the steps that the City of Fredericton has taken to establish an infrastructure asset management program and the obstacles that had to be overcome". | Adoption of a corporate approach to AM in the city of Brimbank as a technical function. | Identification of the required levels of service, "community consultation, condition survey, data management", LCC, "project evaluation, works programming and asset performance monitoring etc" |
| SOURCE | Assetivity (2015d) | Murali (2007) | Jamer (2019) | Godau (2008) | Hossain (2007) |

For example, in the case study CS02 (Asset Management audit: strategy development and implementation) (ASSETIVITY, 2015a), the AM action *"CBH identified the PAS 55:2008 asset management 'standard' as a suitable benchmark" and needed to align its AMS "with the requirements of this standard and 'best appropriate' practice"* was easily associated with the AM key-process 'Technical Standards & Legislation', that means "The processes used by an organization to ensure its asset management activities are compliant with the relevant technical standards and legislation" (GFMAM, 2014). On the other hand, the AM action *"Established a basis for informed decision making about the organisation's assets, including both construction and disposal and based on utilisation and condition data"* was interpreted to be related to the 'Capital Investment Decision-Making' key-process, which means "The processes and decisions to evaluate and analyse scenarios for decisions related to capital investments of an organization … and/or replacements of assets at end of life (CAPEX sustaining programs)" (GFMAM, 2014).

**Step 2:** To identify the benefits for business, an analysis was carried out for each case study, based on an interpretation of the achieved or expected results, that are a consequence of the implemented AM actions.

As in the previous step, the interpretive analysis was justified due to the association between the achieved result and the 'benefits for business' which was not always evident, requiring interpretation as well. For example, in the case study CS06 (Maintenance & reliability improvement program) (ASSETIVITY, 2015c), the result *The program "provided PanAust operations with a comprehensive set of maintenance strategies to ensure equipment function is preserved, and a baseline for performance measurement and improvement"* was logically associated with the 'Improved efficiency and effectiveness' benefit for business, that means "Reviewing and improving processes, procedures and asset performance can improve efficiency and effectiveness, and the achievement of organizational objectives" (ISO, 2014a). In contrast, the result *"The equipment reliability improvement program was to eliminate the major causes of downtime by focusing on equipment that most impacted production output and cost targets"* was inferred to be related to 'Improved services and outputs' benefit for business, which means "assuring the performance of assets can lead to improved services or products that consistently meet or exceed the expectations of customers and stakeholders" (ISO, 2014a).

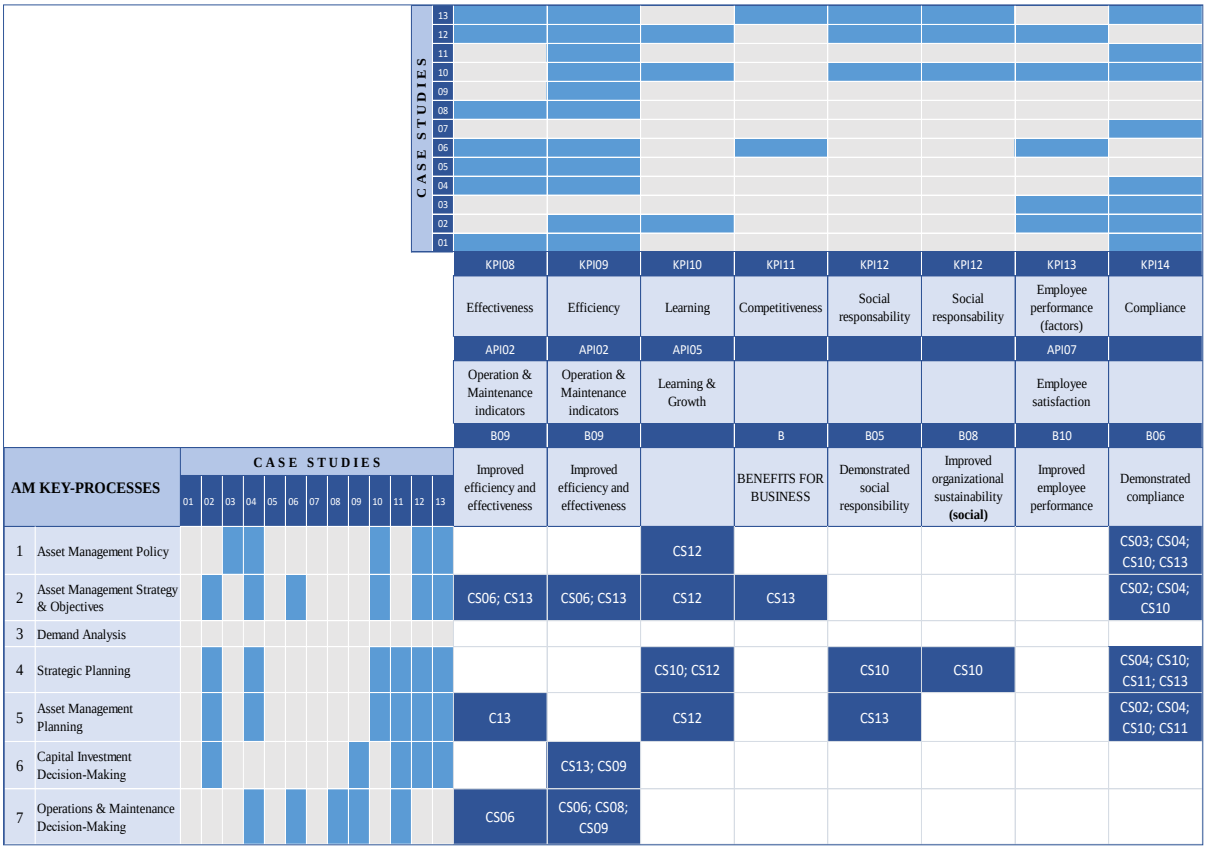
In regard to 'Improved organisational sustainability' (B08) benefit for business, it is known that the physical AM practices, as discussed by Maletič et al. (2018), links to sustainability performance, providing empirical contribution in a significant and positive way.

It is important to consider that sustainability is concerned about the social, economic and environmental dimensions.

For the purpose of this research, to clearly exhibit this contribution from these three dimensions, the B08 benefit for business had been evidenced separately in the analysis of the case studies.

**Step 3:** In this step, an interpretative analysis, based on the results of Steps 1 and 2, was developed for each case study, and the 'benefits for business' were related to the AM actions that gave rise to them. A summary overview of the evidence of the relationships between AM key-process and benefits for business, APIs and KPIs is displayed in Figure 28.

Figure 28 - Evidence of the relationships between AM key-process and benefits for business, APIs and KPIs (overall summary)



| | AM KEY-PROCESSES | CASE STUDIES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | | | | |
| | | | | | | | | | | | | | | | KPI08 | KPI09 | KPI10 | KPI11 |
| | | | | | | | | | | | | | | | Effectiveness | Efficiency | Learning | Competitiveness |
| | | | | | | | | | | | | | | | API02 | API02 | API05 | |
| | | | | | | | | | | | | | | | Operation & Maintenance indicators | Operation & Maintenance indicators | Learning & Growth | |
| | | | | | | | | | | | | | | | B09 | B09 | | B |
| | | | | | | | | | | | | | | | Improved efficiency and effectiveness | Improved efficiency and effectiveness | | BENEFITS FOR BUSINESS |
| 1 | Asset Management Policy | | | | | | | | | | | | | | | | CS12 | |
| 2 | Asset Management Strategy & Objectives | | | | | | | | | | | | | | CS06; CS13 | CS06; CS13 | CS12 | CS13 |
| 3 | Demand Analysis | | | | | | | | | | | | | | | | | |
| 4 | Strategic Planning | | | | | | | | | | | | | | | | CS10; CS12 | |
| 5 | Asset Management Planning | | | | | | | | | | | | | | C13 | | CS12 | |
| 6 | Capital Investment Decision-Making | | | | | | | | | | | | | | | CS13; CS09 | | |
| 7 | Operations & Maintenance Decision-Making | | | | | | | | | | | | | | CS06 | CS06; CS08; CS09 | | |

| | AM KEY-PROCESSES | KPI12 | KPI12 | KPI13 | KPI14 |
|---|---|---|---|---|---|
| | | Social responsability | Social responsability | Employee performance (factors) | Compliance |
| | | | | API07 | |
| | | | | Employee satisfaction | |
| | | B05 | B08 | B10 | B06 |
| | | Demonstrated social responsibility | Improved organizational sustainability **(social)** | Improved employee performance | Demonstrated compliance |
| 1 | Asset Management Policy | | | | CS03; CS04; CS10; CS13 |
| 2 | Asset Management Strategy & Objectives | | | | CS02; CS04; CS10 |
| 3 | Demand Analysis | | | | |
| 4 | Strategic Planning | CS10 | CS10 | | CS04; CS10; CS11; CS13 |
| 5 | Asset Management Planning | CS13 | | | CS02; CS04; CS10; CS11 |
| 6 | Capital Investment Decision-Making | | | | |
| 7 | Operations & Maintenance Decision-Making | | | | |

Source: Lima, McMahon and Costa (2020)

It is important to note that although the case study's identity (id) is shown in both lines and columns in Figure 28, it does not represent a cross case studies analysis. The analysis was performed separately for each case study.

**Step 4:** In this step, the relationships between the 'benefits for business', the APIs and the KPIs, as illustrated and detailed in Figure 25 and 26, were analysed for the case studies.

**Step 5**: In considering the results obtained on Steps 3 and 4 as an input, the relationship between benefits for business, APIs and KPIs is obtained, as shown in Tables 28 and 29. For each AM key-process that has one or more identified AM actions, there is one or more associated benefits, which in turn are associated with an API and/or a KPI. For example, the case studies CS02, CS04, CS10 and CS11 presented AM actions evidence related to the AM key-process 5 – 'Asset Management Planning', as well as results associated with benefit B06 – 'Demonstrated Compliance'. From Step 4, it is possible to relate B06 with the business performance indicator KPI14 – Compliance.

Table 28 - The relationship between AM process and Business Performance (KPI01 - KPI08)

| BUSINESS PERFORMANCE | | ASSET PERFORMANCE | | AM KEY PROCESSES | | FREQ |
|---|---|---|---|---|---|---|
| KPI01 | Financial/ profitability | API03 | AM finances indicators | 38 | Asset Costing & Valuation | 0,38 |
| | | | | 6 | Capital Investment Decision-Making | 0,23 |
| | | | | 7 | Operations & Maintenance Decision-Making | 0,23 |
| | | | | 33 | Sustainable Development | 0,15 |
| | | | | 25 | Data & Information Management | 0,08 |
| | | | | 35 | Assets Performance & Health Monitoring | 0,08 |
| KPI02 | Costumers'/ business partiners' satisfaction | API06 | Customer satisfaction | 4 | Strategic Planning | 0,08 |
| | | | | 20 | Fault & Incident Response | 0,08 |
| | | | | 37 | Management Review, Audit & Assurance | 0,08 |
| KPI03 | Quality of products and services | API02 | Operation & Maintenance indicators | 15 | Maintenance Delivery | 0,38 |
| | | | | 24 | Asset Information Systems | 0,23 |
| | | | | 25 | Data & Information Management | 0,23 |
| | | | | 37 | Management Review, Audit & Assurance | 0,23 |
| | | | | 5 | Asset Management Planning | 0,15 |
| | | | | 17 | Asset Operations | 0,15 |
| | | | | 35 | Assets Performance & Health Monitoring | 0,15 |
| | | | | 36 | Asset Management System Monitoring | 0,15 |
| | | | | 1 | Asset Management Policy | 0,08 |
| | | | | 7 | Operations & Maintenance Decision-Making | 0,08 |
| | | | | 11 | Technical Standards & Legislation | 0,08 |
| | | | | 14 | Configuration Management | 0,08 |
| | | | | 16 | Reliability Engineering | 0,08 |
| | | | | 19 | Shutdown & Outage Management | 0,08 |
| | | | | 20 | Fault & Incident Response | 0,08 |
| | | | | 28 | Organizational Structure | 0,08 |
| KPI04 | Productivity | API03 | AM finances indicators | NO EVIDENCE | | |
| KPI05 | Flexibility | | | 34 | Management of Change | 0,38 |
| | | | | 39 | Stakeholder Engagement | 0,31 |
| | | | | 27 | Asset Management Leadership | 0,08 |
| | | | | 30 | Competence Management | 0,08 |
| KPI06 | Innovation | API05 | Learning & Growth | NO EVIDENCE | | |
| KPI07 | Environmental responsability/ safety | API04 | HSE indicators | 31 | Risk Assessment and Management | 0,62 |
| | | | | 32 | Contingency Planning & Resilience Analysis | 0,08 |
| | | | | 35 | Assets Performance & Health Monitoring | 0,08 |
| | | | | 33 | Sustainable Development | 0,08 |
| | | | | 31 | Risk Assessment and Management | 0,08 |
| KPI08 | Effectiveness | API01 | Asset effectiveness indicators | 35 | Assets Performance & Health Monitoring | 0,15 |
| | | | | 37 | Management Review, Audit & Assurance | 0,15 |
| | | | | 16 | Reliability Engineering | 0,08 |
| | | | | 11 | Technical Standards & Legislation | 0,08 |
| | | | | 24 | Asset Information Systems | 0,08 |
| | | | | 25 | Data & Information Management | 0,08 |
| | | | | 31 | Risk Assessment and Management | 0,08 |
| | | API02 | Operation & Maintenance indicators | 15 | Maintenance Delivery | 0,31 |
| | | | | 16 | Reliability Engineering | 0,15 |
| | | | | 2 | Asset Management Strategy & Objectives | 0,15 |
| | | | | 22 | Asset Information Strategy | 0,15 |
| | | | | 25 | Data & Information Management | 0,15 |
| | | | | 5 | Asset Management Planning | 0,08 |
| | | | | 7 | Operations & Maintenance Decision-Making | 0,08 |
| | | | | 24 | Asset Information Systems | 0,08 |
| | | | | 31 | Risk Assessment and Management | 0,08 |
| | | | | 35 | Assets Performance & Health Monitoring | 0,08 |
| | | | | 37 | Management Review, Audit & Assurance | 0,08 |

Table 29 - The relationship between AM process and Business Performance (KPI09 – KPI14)

| BUSINESS PERFORMANCE | | ASSET PERFORMANCE | | | AM KEY PROCESSES | FREQ |
|---|---|---|---|---|---|---|
| KPI09 | Efficiency | API02 | Operation & Maintenance indicators | 25 | Data & Information Management | 0,46 |
| | | | | 15 | Maintenance Delivery | 0,38 |
| | | | | 16 | Reliability Engineering | 0,23 |
| | | | | 7 | Operations & Maintenance Decision-Making | 0,23 |
| | | | | 22 | Asset Information Strategy | 0,23 |
| | | | | 24 | Asset Information Systems | 0,23 |
| | | | | 30 | Competence Management | 0,23 |
| | | | | 2 | Asset Management Strategy & Objectives | 0,15 |
| | | | | 6 | Capital Investment Decision-Making | 0,15 |
| | | | | 17 | Asset Operations | 0,15 |
| | | | | 31 | Risk Assessment and Management | 0,15 |
| | | | | 37 | Management Review, Audit & Assurance | 0,15 |
| | | | | 18 | Resource Management | 0,08 |
| | | | | 19 | Shutdown & Outage Management | 0,08 |
| | | | | 35 | Assets Performance & Health Monitoring | 0,08 |
| | | | | 36 | Asset Management System Monitoring | 0,08 |
| KPI10 | Learning | API05 | Learning & Growth | 4 | Strategic Planning | 0,15 |
| | | | | 1 | Asset Management Policy | 0,08 |
| | | | | 2 | Asset Management Strategy & Objectives | 0,08 |
| | | | | 5 | Asset Management Planning | 0,08 |
| KPI11 | Competitiveness | | | 2 | Asset Management Strategy & Objectives | 0,08 |
| | | | | 7 | Operations & Maintenance Decision-Making | 0,08 |
| | | | | 33 | Sustainable Development | 0,08 |
| KPI12 | Social responsability | | | 33 | Sustainable Development | 0,23 |
| | | | | 33 | Sustainable Development | 0,23 |
| | | | | 4 | Strategic Planning | 0,08 |
| | | | | 5 | Asset Management Planning | 0,08 |
| | | | | 30 | Competence Management | 0,08 |
| | | | | 34 | Management of Change | 0,08 |
| | | | | 4 | Strategic Planning | 0,08 |
| | | | | 30 | Competence Management | 0,08 |
| | | | | 32 | Contingency Planning & Resilience Analysis | 0,08 |
| | | | | 34 | Management of Change | 0,08 |
| KPI13 | Employee performance (factors) | API07 | Employee satisfaction | 30 | Competence Management | 0,46 |
| | | | | 34 | Management of Change | 0,15 |
| KPI14 | Compliance | | | 11 | Technical Standards & Legislation | 0,38 |
| | | | | 1 | Asset Management Policy | 0,31 |
| | | | | 4 | Strategic Planning | 0,31 |
| | | | | 5 | Asset Management Planning | 0,31 |
| | | | | 37 | Management Review, Audit & Assurance | 0,31 |
| | | | | 2 | Asset Management Strategy & Objectives | 0,23 |
| | | | | 33 | Sustainable Development | 0,08 |
| | | | | 34 | Management of Change | 0,08 |
| | | | | 36 | Asset Management System Monitoring | 0,08 |

The analysis of the Case Study CS09 (ASSETIVITY, 2015d) is detailed next as an example of how the data were analysed.

## 5.4 EXPLORING THE CASE STUDY CS09[9]

The summary of CS09 data is shown in Table 30 and a detailed analysis following the steps of the Model is depicted next.

[9] This section does not belong to the Lima, McMahon and Costa (2020) article. It was inserted into the thesis to make the analysis of the case studies clearer.

Table 30 - Case Study CS09 Summary

| ID | CS09 |
|---|---|
| CASE STUDY TITLE | CONDUCTOR STRATEGY REVIEW |
| ORGANISATION | Western Power (WP) |
| BUSINESS | Electricity network |
| PROFILE | "Western Power is responsible for building, maintaining and operating the electricity network comprising the South West Interconnected System in Western Australia, covering an area of 261000 square kilometres". |
| PROBLEM | The absence of adequate driver condition information leads to AM decisions that have the potential to result in less efficient investment. |
| AM RELATED ACTION | AM knowledge management to draw out expert knowledge; Change management to improve awareness of specific failure; Competence Management to improve the understanding of the current Program. |
| SOURCE | Assetivity (2015d) |

Source: Adapted from Lima, McMahon and Costa (2020)

**AMBP Model Step 1.1**

Case study CS09 was analysed in terms of four dimensions or elements: context, problem, demand and implemented AM actions. The result is the identification of the AM actions, that were carried out in response to a particular problem of the organisation, as well as the AM key-processes related to these AM actions. An interpretative analysis of the CS09 evidenced six AM actions.

AM action1 – In order to make more efficient investment decisions, WP implemented a program aimed at drawing out expert knowledge from field personal of the organisation.

AM action2 – In the absence of adequate conductor condition information, AM decisions are based on the conductor's age, make or type attributes. To adequately manage its distribution conductors, Western Power acted to obtain accurate and updated knowledge of the conductor's condition, allowing for prudent and efficient AM decisions.

AM action3 – Developing databases to record and report findings, including: • Comparing field personnel observations of conductor condition with samples; • Capturing various factors (including conductor type, material, age and local environmental conditions) and associated conductor condition for specific sections of conductor; and • Mapping results for those specific sections of conductor using detailed network maps.

AM action4 – Coaching Western Power personnel on the techniques used. Cross-functional workshops were developed to draw out expert knowledge from operational personnel of the organisation. Workshops at 22 of Western Power's field depots.

AM action5 – To enhance the understanding of both the condition of the conductors and the factors influencing the condition of the conductors, Western Power initiated a risk-based 'Conductor Strategy Review'. This included a conductor sampling program, historical data analysis and a personnel observation.

AM action6 – A 'Conductor Strategy Review' based on risk was performed.

**AMBP Model Step 1.2**

As a result of the analysis, each of the 6 evidenced AM action was related to one of the 39 **AM key-processes** (Table 22). This relationship was performed by evaluating the similarity of the concept of the AM key-process (GFMAM, 2014) with the AM action. In this example:

- AM action1 was related to AM Key-process 6 (Capital Investment Decision-Making).
- AM action2 was related to AM Key-process 7 (Operations & Maintenance Decision-Making).
- AM action3 was related to AM Key-process 25 (Data & Information Management).
- AM action4 was related to AM Key-process 30 (Competence Management).
- AM action5 was related to AM Key-process 31 (Risk Assessment and Management).
- AM action6 was related to AM Key-process 37 (Management Review, Audit & Assurance).

The result is shown in Table 31.

**AMBP Model Step 2.1:**

In this step, the evidenced benefits which are based on an interpretation of the achieved or expected results and are a consequence of the implementation of the AM actions identified in Step 1, are pointed out. Five **benefits** were evidenced for the CS09:

Evidenced Benefit 1 – Western Power refined AM decisions on managing distribution overhead conductors, optimising ongoing asset management costs.

Evidenced Benefit 2 – With an accurate and up to date knowledge of conductor condition Western Power can make prudent and efficient AM decisions, that result in a more efficient investment.

Evidenced Benefit 3 – A report was produced highlighting insights into conductor failure modes informing several refinements to the current conductor management strategy.

Table 31 - CS09 Evidenced AM Actions and AM Key-processes

| AM KEY-PROCESS | | GFMAM DEFINITION | AM ACTION |
|---|---|---|---|
| **6** | Capital Investment Decision-Making | The processes and decisions to evaluate and analyse scenarios for decisions related to capital investments of an organisation and/or replacements of assets at end of life. | **AM Action1 -** In order to make more efficient investment decisions, WP implemented a program aimed at drawing out expert knowledge from field personal of the organisation. |
| **7** | Operations & Maintenance Decision-Making | The management activities and processes involved in determining the Operations and Maintenance requirements in support of the Asset Management objectives and goals. | **AM Action2 -** In the absence of adequate conductor condition information, AM decisions are based on the conductor's age, make or type attributes.<br>To adequately manage its distribution conductors, Western Power acted to obtain accurate and updated knowledge of the conductor's condition, allowing for prudent and efficient AM decisions. |
| **25** | Data & Information Management | The data and information held within an organisation's asset information systems and the processes for the management and governance of that data and information. | **AM Action3 -** Developing databases to record and report findings, including: • Comparing field personnel observations of conductor condition with samples; • Capturing various factors (including conductor type, material, age and local environmental conditions) and associated conductor condition for specific sections of conductor; and • Mapping results for those specific sections of conductor using detailed network maps. |
| **30** | Competence Management | The process used by an organisation to systematically develop and maintain an adequate supply of competent and motivated people to fulfil its asset management objectives including arrangements for managing competence in the boardroom and the workplace. | **AM Action4 -** Coaching Western Power personnel on the techniques used. Cross-functional workshops were developed to draw out expert knowledge from operational personnel of the organisation. Workshops at 22 of Western Power's field depots. |
| **31** | Risk Assessment and Management | The policies and processes for identifying, quantifying and mitigating risk and exploiting opportunities. | **AM Action5 -** To enhance the understanding of both the condition of the conductors and the factors influencing the condition of the conductors, Western Power initiated a risk-based 'Conductor Strategy Review'. This included a conductor sampling program, historical data analysis, and a personnel observation. |
| **37** | Management Review, Audit & Assurance | An organisation's processes for reviewing and auditing the effectiveness of its asset management processes and asset management system. | **AM Action6** - A 'Conductor Strategy Review' based on risk was performed. |

Source: This research (2020)

Evidenced Benefit 4 –A report highlighting insights into conductor failure modes informing a number of refinements to the current conductor management strategy was provided; a database comparing observed conductor condition with samples taken from the Conductor Sampling Program was provided; a data cleansing and analysis across the total conductor

population database was provided; and a database of field personnel feedback categorised by conductor type was produced.

Evidenced Benefit 5 – Western Power with accurate and up to date knowledge of conductor condition, improved understanding of conductor failure modes across the network. The 'Grass Roots' program with the aim of providing failure mode information would assist in improving Western Power's understanding of the problem under analysis.

Table 32 - CS09 Evidenced benefits

| BENEFITS FOR BUSINESS REF: ISO 55000:2014 | | | EVIDENCED BENEFITS |
|---|---|---|---|
| B1 | Improved financial performance | Improving the return on investments and reducing costs can be achieved while preserving asset value and without sacrificing the short or long-term realisation of organisational objectives. | Evidenced benefit 1 - Western Power refined AM decisions on managing distribution overhead conductors, optimising ongoing asset management costs. |
| B2 | Informed asset investment decisions | Enabling the organisation to improve its decision making and effectively balance costs, risks, opportunities and performance; | Evidenced benefit 2 - With an accurate and up to date knowledge of conductor condition Western Power can make prudent and efficient AM decisions, that result in a more efficient investment. |
| B3 | Managed risk | Reducing financial losses, improving health and safety, good will and reputation, minimizing environmental and social impact, can result in reduced liabilities such as insurance premiums, fines and penalties. | Evidenced benefit 3 - A report was produced highlighting insights into conductor failure modes informing a number of refinements to the current conductor management strategy. |
| B9 | Improved efficiency and effectiveness | Reviewing and improving processes, procedures and asset performance can improve efficiency and effectiveness, and the achievement of organisational objectives. | Evidenced benefit 4 - A report highlighting insights into conductor failure modes informing a number of refinements to the current conductor management strategy was provided; a database comparing observed conductor condition with samples taken from the Conductor Sampling Program was provided; a data cleansing and analysis across the total conductor population database was provided; and a database of field personnel feedback categorised by conductor type was produced. |
| B10 | Improved employee performance | Through improved employee competence, awareness and confidence, in the understanding of AM and the benefits it brings for business and d how to go to achieve them. | Evidenced benefit 5 - WP with accurate and up to date knowledge of conductor condition, improved understanding of conductor failure modes across the network. The 'Grass Roots' program with the aim of providing failure mode information would assist in improving Western Power's understanding of the problem under analysis. |

Source: This research (2020)

**AMBP Model Step 2.2**

As a result of the analysis, each of the five evidenced benefits was related to one of the 12 **benefit for business** (Table 24). This relationship was performed by evaluating the

similarity of the **concept** of the benefit for business (ISO55000, 2014) with the evidenced benefit, and the result is shown in Table 32.

**AMBP Model Step 3:**

Based on the results of Steps 1 and 2, an interpretative analysis was developed. The objective is to highlight where AM key-processes are improved by an AM action and the respective 'benefit for business' achieved because of this AM action. A partial view of the result for **CS09** is shown in Figure 29.

The darker blue cells, identified with the 'AM Key-process' x 'Benefit for business' link, are the evidence for CS09 in Figure 28. As Figure 28 is an overall summary, only the 'AM Key-process 6' x 'Benefit for business B9' and 'AM Key-process 7' x 'Benefit for business B9' evidence are shown (see the dark red ellipse). Figure 28 is reproduced in Figure 30 highlighting the evidence for CS09.

**AMBP Model Step 4:**

After the link between 'AM Key-process' and 'benefit for business' has been settled, as previously described, the relationship between 'AM Key-processes', APIs and KPIs is established for each evidenced link (the dark blue cells in Figure 30). Regarding the evidence exemplified for the case study CS09 (highlighted in red on Figure 29 and on Figure 30) the relationship is depicted bellow.

In Figure 30, for CS09, the 'AM Key-process 6' and 'AM Key-process 7' are linked to 'benefit for business B09'.

From Figure 31, a partial view of Figure 26, 'benefit for business B09' is related to API02 and KPI09, considering the assumption:

> *"Best practice in AM results in good* ***operation and maintenance indicators - API02*** *(Accurate report with information on availability, reliability, preventive maintenance, corrective maintenance, systems shutdown, outage and restart and associated costs (PARIDA, 2012)) which can lead to the benefits for business ……. and: '****Improved efficiency and effectiveness' - B09*** *(Meeting continuous improvement for business efficiency and effectiveness, reviewing and improving processes, procedures and asset performance (ILORI, 2015)). Other consequences are an improvement of* ***Efficiency - KPI09*** *(Improved utilisation of resources to provide desired outputs (MA et al., 2014)), ……" (LIMA; McMAHON; COSTA, 2020).*

**AMBP Model Step 5:**

Table 28 shows the percentage of the evidenced relationships between AM Key-process, benefits for business, API and KPI, related to all the analysed case studies. Note that the evidence was observed in different organisations with different strategies, from different sectors.

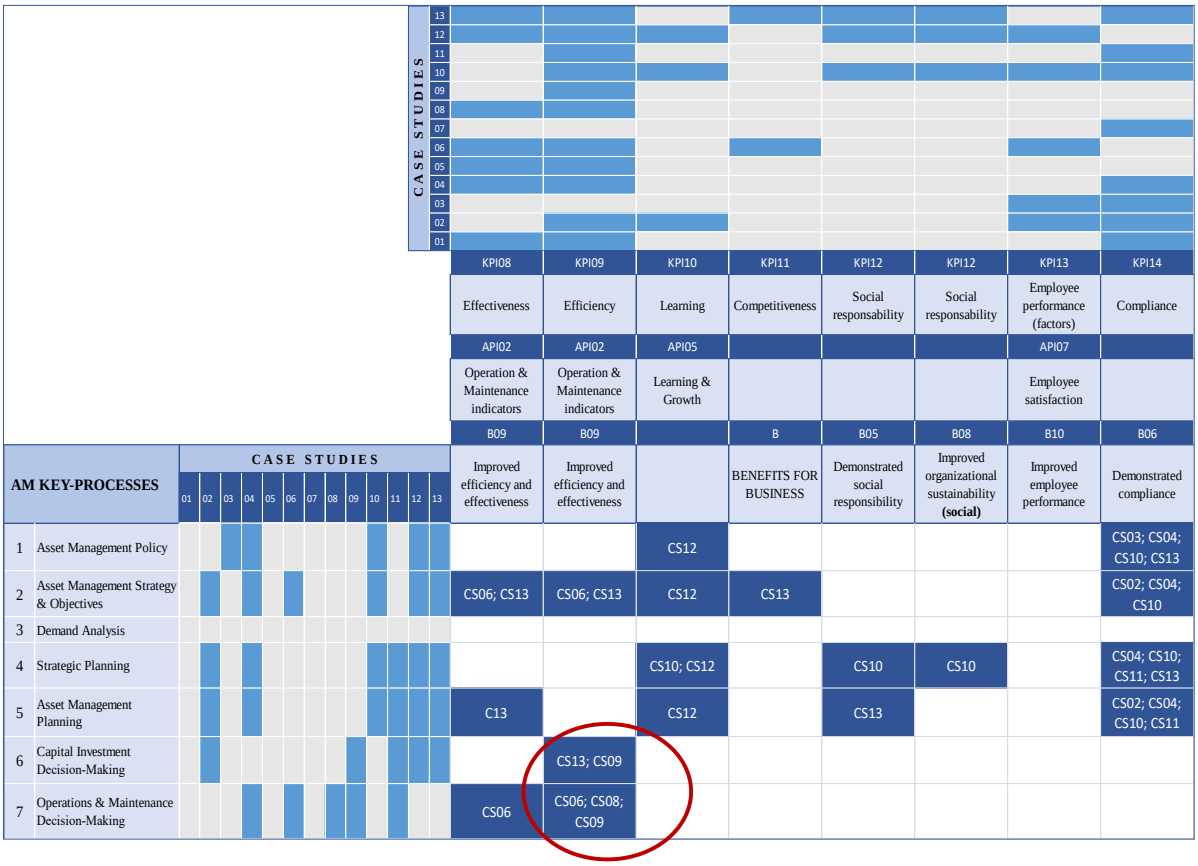
Figure 29 - AM Key-process x Benefit for business link for CS09 (partial view)

| CASE STUDY CS09 | | | BENEFITS FOR BUSINESS | | |
|---|---|---|---|---|---|
| | | | **B3** Managed risk | **B9** Improved efficiency and effectiveness | **B10** Improved employee performance |
| **AM KEY-PROCESS** | | **AM ACTION** | **Evidenced benefit 3** - A report was produced highlighting insights into conductor failure modes informing a number of refinements to the current conductor management strategy. | **Evidenced benefit 4** - A report highlighting insights into conductor failure modes informing a number of refinements to the current conductor management strategy was provided; a database comparing observed conductor condition with samples taken from the Conductor Sampling Program was provided; a data cleansing and analysis across the total conductor population database was provided; and a database of field personnel feedback categorised by conductor type was produced. | **Evidenced benefit 5** - WP with accurate and up to date knowledge of conductor condition, improved understanding of conductor failure modes across the network. The 'Grass Roots' program with the aim of providing failure mode information would assist in improving Western Power's understanding the problem under analisys. |
| **6** | Capital Investment Decision-Making | **AM Action1** - In order to make more efficient investment decisions, WP implemented a program aimed at drawing out expert knowledge from field personal of the organization. | | AM Key-process 6 x Benefit for business B9 | |
| **7** | Operations & Maintenance Decision-Making | **AM Action2** - In the absence of adequate conductor condition information, AM decisions are based on the conductor's age, make or type attributes. To adequately manage its distribution conductors, Western Power acted to obtain accurate and updated knowledge of the conductor's condition, allowing for prudent and efficient AM decisions. | | AM Key-process 7 x Benefit for business B9 | |
| **25** | Data & Information Management | **AM Action3** - Developing databases to record and report findings, including: • Comparing field personnel observations of conductor condition with samples; • Capturing various factors (including conductor type, material, age and local environmental conditions) and associated conductor condition for specific sections of conductor; and • Mapping results for those specific sections of conductor using detailed network maps. | | AM Key-process 25 x Benefit for business B9 | |
| **30** | Competence Management | **AM Action4** - Coaching Western Power personnel on the techniques used. Cross functional workshops were developed to draw out expert knowledge from operational personnel of the organisation. Workshops at 22 of Western Power's field depots. | | | AM Key-process 30 x Benefit for business B10 |

Source: This research (2021)

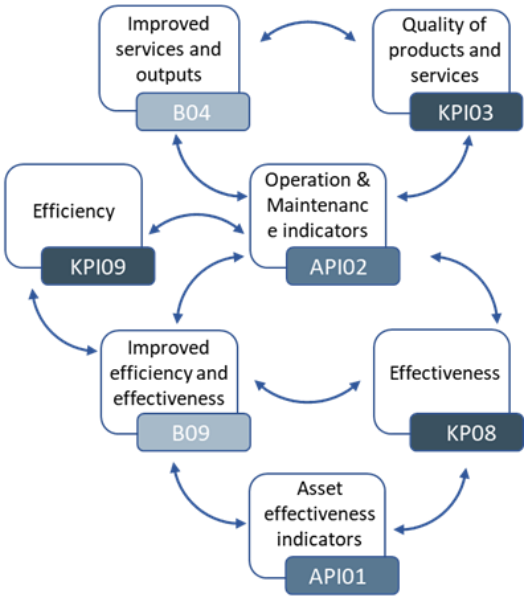
In the example, the link among 'AM Key-process 6' and 'benefit for business B09' and 'asset performance indicator API02' and 'business performance indicator KPI09' was evidenced by 2 case studies (CS09 and CS13), corresponding to 15%. The 'AM Key-process 7' and 'benefit for business B09' and 'asset performance indicator API02' and 'business performance indicator KPI09' link was evidenced by 3 case studies (CS06, CS08 and CS09), corresponding to 23%.

Figure 30 - Evidence relationships for CS09




Source: Adapted from Lima, McMahon and Costa (2020)

Figure 31 - Relationship between Benefits for business, API and KPI (partial view)




Source: Adapted from Lima, McMahon and Costa (2020)

## 5.5 RESULTS AND DISCUSSION

The main contribution of this research is the establishment of the relationships between ‘asset management’ and ‘business performance’, obtained during the analysis of AM case studies, implemented in asset-intensive organisations from different sectors of the economy.

Previous research by Attwater et al., (2014) proposes to measure the performance of asset management systems through a framework and an asset performance map. Although both, the framework proposed by Attwater et al., (2014) and the AMBP Model, consider the complete asset life cycle and use the 39 AM key-processes from GFMAM to establish a link of these key-processes with APIs and KPIs, the methodologies and focus on the analysis and the scope of the relationship are quite different.

Attwater et al., (2014) identify the AM key-activities and their intended outcomes, measured by the APIs. Also, the authors propose to show how those outcomes link to business performance, in three perspectives that must be identified by the organisation: financial, performance and risk. However, the strength of the relationship between APIs and KPIs is difficult to determine, as the KPIs are not displayed.

In contrast, the methodology proposed by the AMBP Model is to establish relationships between AM key-processes and business KPIs, in asset-intensive organisations, through the performance measures of the AM key-processes outputs, which are ‘valued assets’ and ‘benefits for business’. The former is represented by the APIs and the latter is measured by the KPIs, as illustrated in Figure 22. The APIs and KPIs are related to each other by the proximity of concepts from the literature, as shown in Figures 25 and 26. AMBP Model utilizes AM case studies of different sectors of the economy as the source of the evidence.

Some AM key-processes have been identified as contributing to the business from the analysis of each of the case studies. The most significant relationships between the business KPIs and the APIs and the AM key-processes, based on the evidence of the 13 case studies, are shown in Table 33. In this condition, 8 business KPIs associated with 6 APIs and 14 AM key-processes were identified.

An analysis of Table 33 suggests that if the organisation intends to improve its 'Environmental responsibility/safety' business indicator (KPI07), it should invest in AM actions related to the 'Risk Assessment and Management' key-process, which could be, for example, risk identification, analysis, assessment and treatment. This relationship was identified in 8 of 13 case studies, at a higher frequency compared to the other relationships.

Another example would be investing in AM actions related to the key processes 'Technical Standards & Legislation', 'Asset Management Policy', 'Strategic Planning', 'Asset Management Planning' and 'Management Review, Audit & Assurance', if the organisation has, as a priority, the improvement of the Compliance business indicator (KPI14). A third example is a linkage between the 'Financial /profitability' (KPI01) with the 'AM finances indicators' (API03). Understanding the asset life cycle is key to making longer-term strategic decisions about the asset performance in terms of cost, represented here by 'Asset Costing & Valuation' (AM key-process 38). The new standard ISO 55010, which has been released recently, helps to provide some guidance in the alignment between financial and non-financial functions in asset management (ISO, 2019). The complete result of the relationship between AM key-processes and Business Performance KPIs is shown in Table 28 and 29.

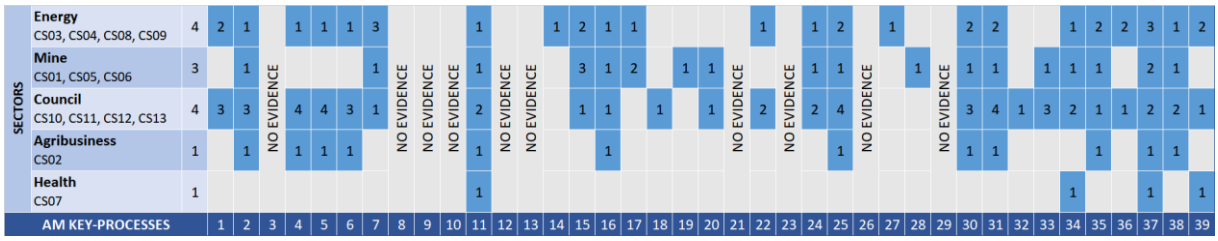
Table 33 - The most significative relationship between KPIs and AM key-processes

| BUSINESS PERFORMANCE | | ASSET PERFORMANCE | | AM KEY PROCESSES | | FREQ |
|---|---|---|---|---|---|---|
| KPI01 | Financial/ profitability | API03 | AM finances indicators | 38 | Asset Costing & Valuation | 38% |
| KPI03 | Quality of products and services | API02 | Operation & Maintenance indicators | 15 | Maintenance Delivery | 38% |
| KPI05 | Flexibility | | | 34 | Management of Change | 38% |
| | | | | 39 | Stakeholder Engagement | 31% |
| KPI07 | Environmental responsibility/ safety | API04 | HSE indicators | 31 | Risk Assessment and Management | 62% |
| KPI08 | Effectiveness | API02 | Operation & Maintenance indicators | 15 | Maintenance Delivery | 31% |
| KPI09 | Efficiency | API02 | Operation & Maintenance indicators | 25 | Data & Information Management | 46% |
| | | | | 15 | Maintenance Delivery | 38% |
| KPI13 | Employee performance | API07 | Employee satisfaction | 30 | Competence Management | 46% |
| KPI14 | Compliance | | | 11 | Technical Standards & Legislation | 38% |
| | | | | 1 | Asset Management Policy | 31% |
| | | | | 4 | Strategic Planning | 31% |
| | | | | 5 | Asset Management Planning | 31% |
| | | | | 37 | Management Review, Audit & Assurance | 31% |

Source: Lima, McMahon and Costa (2020)

The sectors of the economy (energy, mining, local council, agribusiness and health), which the case studies were the object of analysis, and respective evidenced AM key-processes, are shown in Figure 32.

Figure 32 - The sectors of the economy and the evidenced AM key-processes




Source: Lima, McMahon and Costa (2020)

The figure shows the number of case studies in each sector and the number of evidences for each AM key-process per sector. Of the 39 AM key-processes, 10 key-processes were not evidenced in the analysis of the case studies, probably because of the context of the organisation in facing a specific business problem, but this should be not relevant. The ten key-processes where no AM actions could be related are listed in Table 34.

Table 34 - AM key processes not evidenced in case studies

| ID | AM KEY PROCESS |
|---|---|
| 03 | Demand Analysis |
| 08 | Lifecycle Value Realisation |
| 09 | Resourcing Strategy |
| 10 | Shutdown & Outage Strategy |
| 12 | Asset Creation & Acquisition |
| 13 | Systems Engineering |
| 21 | Asset Decommissioning and Disposal |
| 23 | Asset Information Standards |
| 26 | Procurement & Supply Chain Management |
| 29 | Organisational Culture |

Source: Lima, McMahon and Costa (2020)

Particularly, for the key-processes shown in Table 34, Systems Engineering requires further examination. Systems Engineering has several definitions and objectives in the literature, such as “An interdisciplinary, collaborative approach to derive, evolve and verify a life cycle balanced system solution which satisfies customer expectations and meets public acceptability” (GFMAM, 2014). Systems engineering means the effort to “integrate reliability,

maintainability, usability (human factors), safety, producibility, supportability, sustainability, disposability and other such factors into a total engineering effort to meet cost, schedule and technical performance objectives" (BLANCHARD; BLYLER, 2016). Although the large scope of these definitions can include several AM actions, as the term 'Systems Engineering' was not made explicit in any of the case studies, it was decided not to consider it in establishing links with the benefit for business, nor with APIs and KPIs. Therefore, the 'Systems Engineering' AM key-process was marked as 'not evidenced' in the case studies analysis (Figure 32).

In a similar analysis to Systems Engineering, which is normally used at the front end of the acquisition stage of AM process for the procurement of significant assets, two other key processes appear to justify the status of 'no evidence', in Figure 32. They are: Asset Creation & Acquisition and Procurement & Supply Chain Management. As each of the case studies dealt with problems around an existing asset, key-processes that may be important in the acquisition stage of an AM strategy may not be evident.

The types of industry sectors chosen for the case studies clearly influence the types of KPIs identified as important for business performance. For sectors that include service industries, creating value from intangible assets may require more focus on KPIs such as quality, for example. Other sectors, such as mines, where a tangible output is being provided from tangible assets with significant capital expenditure, financial and safety KPIs will have a different focus. Innovation may be required of an organisation to adapt to the change being forced upon the organisation, due to internal or external factors. In this instance, innovation may be identified as the KPI (HAMMER, 2004). It is important to consider those intangible relationships may exist, but do not have them identified from the CS analysis, as they are either related to non-financial KPIs or the links are shown elsewhere (MEIER et al. 2013).

In the analysis, AM key-process 7 (Operations & Maintenance Decision-Making) and 37 (Management Review, Audit and Assurance), in Figure 32, are mentioned for 3 out of the 4 case studies from the energy sector, and each of the organisations dealt with different objectives and different contexts. AM key-process 37 is indicated across all the sectors of the case studies. This may be due to the level of regulatory control and legislation in these industry sectors. Further research will be undertaken to ascertain the reasons for this grouping.

For each case study, the analysis made it possible to connect the associated AM key-process, Table 22, as well as the 12 benefits for business shown in Table 24, with the APIs, Table 23, and KPIs, Figure 23. To exemplify the findings, some evidence of how these relationships are justified is detailed next.

**Example 1:** KPI07 – 'Environmental responsibility/safety' and API04 – 'HSE indicators' with AM Key-process 31 – 'Risk Assessment and Management' was evidenced by 62% of the analysed case studies (CS01, CS02, CS08-CS13).

To illustrate this relationship, in the CS01 case study (ASSETIVITY 2016a) Energy Resources Australia (ERA) needed to identify the actions for a restart of the plant and assure that there were no significant systemic risks that required its attention. The AM actions were evidenced on the 'Risk Assessment and Management' (AM key-process 31), such as: "*An assessment of equipment condition in order to identify areas where current asset condition represented a significant risk to plant integrity, safety and environment*" (ASSETIVITY 2016a); recommendations regarding the actions required to address any asset integrity and AM issues were identified; "*An assessment of Operating Practices and Processes in order to identify potential areas where these may contribute to significant operational safety and/or environmental risks*" (ASSETIVITY 2016a) was realised.

As a benefit for business (B03 - Managed risk), ERA obtained: A risk-based review to assure that there were no significant systemic risks; "*An assessment of Asset Criticality is required in order to focus attention on those assets could have the greatest impact on Health, Safety and the Environment*" (ASSETIVITY 2016a), which could improve the 'KPI07- Environmental responsibility/safety' business indicator, as well as the 'API04 - HSE indicators' asset performance indicator.

**Example 2:** KPI09 – 'Efficiency' and API02 – 'Operation & Maintenance indicators' with AM Key-process 25 – 'Data & Information Management' was evidenced by 46% of the analysed case studies (CS06; CS08; CS09; CS10; CS12; CS13).

This relationship is illustrated by the CS09 case study (ASSETIVITY 2015d). In this CS, the absence of adequate driver condition information leads Western Power, an electricity network company, to practice AM actions, such as: "*Developing databases to record and report findings, including: Comparing field personnel observations of conductor condition with samples…; Capturing various factors (including conductor type, material, age and local environmental conditions) and associated conductor condition for specific sections of conductor; and Mapping results for those specific sections of conductor using detailed network maps*" (ASSETIVITY 2015d).

As a benefit for business (B9- Improved efficiency and effectiveness), Western Power, with accurate and up to date knowledge of electrical conductor condition, improved understanding of conductor failure modes across the network. The 'Grass Roots' program, with the aim of providing failure mode information, would assist in improving Western Power's

understanding of the problem under analysis and, consequently, improve ‘API02- Operation & Maintenance’ asset indicator and ‘KPI09- Efficiency’ business indicator.

**Example 3**: KPI01 – ‘Financial/ profitability’ and API03 - ‘AM finances indicators’ with AM Key-process 38 - ‘Asset Costing & Valuation’ was evidenced by 38% of the analysed case studies (CS02; CS05; CS08; CS10; CS11).

This relationship is illustrated by the CS10 case study (MURALI, 2007). The local government of the City of Charles Sturt, Adelaide, South Australia, developed and implemented a Strategic Asset Management (SAM) and discussed methods by which Strategic AM can be made simple, sensible and practical. “*Based on service levels, operation and maintenance cost information (that was available from the accounts and finance system at the time)*” (MURALI, 2007), a broad base asset life cycle costing (LCC) was developed as an AM action.

As a benefit for business (B1 - Improved financial performance), the City of Charles Sturt council used AM plans “*as a tool for assisting Asset Managers to document the current status of the assets (that is levels of service, demand forecasting, risk analysis, life cycle costing and long term financial planning)*” (MURALI, 2007). A 20-year “*financial forecast for operations and maintenance, renewal and upgrades were prepared based on asset data, LCC and risk analysis*” (MURALI, 2007). Doing this it was expected to increase ‘API03 - AM finances indicators’ asset performance indicator and, therefore, the ‘KPI01 - Financial/ profitability’ business indicator.

**Example 4**: KPI14 – ‘Compliance’ with AM Key-process 37 – ‘Management Review, Audit & Assurance’ was evidenced by 31% of the analysed case studies (CS01; CS02; CS04; CS07).

This relationship is illustrated by the CS04 case study (ASSETIVITY, 2016c). Hydro Tasmania's asset base was aging, “*creating challenges for the organisation from reducing performance, increasing maintenance burdens, increasing risk and the resulting repair/replace decision making*” (ASSETIVITY, 2016c). Assessment of Hydro Tasmania's maturity across the ISO 55001 categories, to identify opportunities by the key-process ‘KP37 - Management Review, Audit & Assurance’ resulted in the review of Hydro Tasmania’s processes.

As a benefit for business (B6 - Demonstrated compliance), “*the opportunities to close identified gaps that would allow Hydro Tasmania to achieve an assessment of Competent required for full compliance and future certification*” (ASSETIVITY, 2016c) were identified. This would help in improving Hydro Tasmania's understanding of the particular asset performance problem under analysis and, therefore, improve ‘KPI09 - Efficiency’ business indicator.

From these four examples, it's noted that the measurement systems must be aligned with business objectives and vision (PARIDA et al., 2015) so actions taken to improve AM processes depend on business strategy and requirements, which vary across different sectors of the economy.

To support this business alignment further, a new standard has been developed to cater for the alignment of financial and non-financial functions in AM (ISO, 2019). Some of the AM key processes may be a part of the strategic AM plan as a longer-term goal rather than in the AM plan as a shorter-term goal (CHAREONSUK; CHANSA-NGAVEJ, 2008; ISO, 2014b; KHUNTIA et al, 2016).

## 5.6 FINAL CONSIDERATIONS

The AMBP Model was designed to identify the existence of relationships between AM – represented by its key-processes, and asset value – measured by asset performance indicators (APIs), and business performance – measured by business key-processes indicators (KPIs). The input data for the AMBP Model comprises (a) evidence of AM actions, performed with the aim to solve a problem or to meet a business objective, and (b) evidence of benefits for business that are a consequence of the AM actions. Both pieces of evidence were collected from 13 AM case studies applied to asset-intensive companies of different sectors of the economy, published in the academic literature or specialized sites. It is important to highlight that, depending on the context of the organisation, different links may be observed as the solution to the faced problem.

The relationships established by the AMBP Model are an important tool to bring up another important aspect: the issue of AM maturity and its contribution to business performance. AM maturity, in one aspect, is being measured in light of how well the organisation follows the AM standards, therefore, if the organisation achieves the expected AM results it will most likely have a good maturity level in AM. This can be reflected by increasing the value of the assets and more benefits for business. However, as discussed in this research, it is not yet possible to state that a good level of maturity in AM leads to a good business outcome, as it may be a prerequisite, but other conditions are also required as well (GFMAM, 2015).

Investments in AM are known to be significant for asset-intensive companies. To improve their performance and obtain better returns, it is extremely useful to understand how AM maturity impacts the business. Thus, it will be possible to focus the investments on AM processes that are relevant to a business context. In other words, to have adequate information

to prioritize which actions, among the various dimensions of the AM process, need to be implemented will support business goals in a more targeted manner. This research suggests the AMBP Model as a first step in seeking to measure the impact of the AM maturity on business performance. This will enable AM investment decisions to be taken by the organisations with higher confidence, based on the desired performance level for the business.

The AMBP Model aims to clarify this issue by providing a helpful path for future studies in this topic, presenting elements that can pave the way for answering the question: 'How does Asset Management maturity impact on business performance?', an issue that remains pertinent in both the academic and business environments. The AMBP model suggests that where a relationship has been established between an AM key process and a business KPI, and if the business KPI is primarily strategic for the organisation, investments should be prioritised in the related AM key-processes.

The main theoretical and practical contributions of this research are: (1) the link between AM key-process and 'benefit for business' as the result of an interpretative analysis by the authors, based on the evidence of the AM case studies; (2) the link between the benefit for business with API and KPI established by the proximity of concepts from the literature, as shown in Figures 25 and 26; (3) the relationship between KPIs with APIs and AM key-processes, through the connection established in the first and second findings. This relationship is an enabler for giving insights to the open question "How does AM maturity impact on business?"; and (4) the proposal of a research agenda where future topics are outlined (based on the result of the application of the AMBP Model, to propose a model to measure the impact of the AM maturity on the business performance).

# 6 CONCLUSION

Asset Management (AM) is, in essence, multidisciplinary and complex as it requires well-established and controlled processes, trained human resources, effective information management, integration between technical and managerial areas and highly committed leadership. Asset-intensive companies deal with significant investments in AM and aim the improvement of their performance to obtain better returns.

As a contribution to this intent, this thesis, **Engineering Asset Management: Problem-solving models to support asset-intensive organisations in the Regulatory and Business Performance contexts,** written in a multi-paper approach, presents three conceptual models to assist asset-intensive organisations in different strategic scenarios.

The conceptual models, 'AM: Where to Start' (Chapter 3), 'AM-RoM' (Chapter 4) and 'Asset Management and Business Performance Relationship Model - AMBP Model' (Chapter 5), contextualized by an Integrated View of the Engineering AM (AM-IV), offer a support for asset-intensive companies to solve AM problems, tailored to specific contexts, in the case, the regulatory and business performance contexts.

Focusing on the procedural-methodological aspect, the AM-IV presents the main AM dimensions, considering its internal and external environments. Relationships among the dimensions are also made explicit, as they are an important aspect for the understanding of the various possibilities that can be considered in technical or managerial models. The three AM Problem-Solving Models, which are the object of this thesis, are categorised by the AM-IV within the same dimension, namely AM Problem-solving Managerial Models.

Furthermore, AM-IV intends to contribute to organisations by offering a better understanding of the complex nature of AM and the possibilities of models that can be designed, to meet specific needs in many scenarios.

The first two models 'AM: Where to Start' and 'AM-RoM' were the result of applied researches and answer the first research question "How to assist an asset-intensive organisation in implementing AM and RM whilst promoting the organisation conformance with the Sector Regulation?". The third one, the 'AMBP Model', was the result of fundamental research and answers the second research question "How to evidence the relationship between AM and business performance in asset-intensive organisations?". It is important to highlight that the problem-solving models do not intend to compete with the established AM models, but to offer a significant contribution to the asset-intensive organisations, which deal with many needs in different contexts, and mainly with large investments.

## 6.1 CONSIDERATIONS ABOUT PROBLEM-SOLVING MODELS

In Asset Management, every scenario has its peculiarities and there is no unique solution that is equally suited to all situations. On the other hand, different solutions can exist for the same decision scenario, as shown by the '**AM: Where to Start**' and the 'Regulation-Oriented Model for Asset Management - **AM-RoM**' models. These two models, although having different approaches, vary in important aspects and have similarities, as well.

Both support an asset-intensive organisation in making decisions about the implementation of asset management and risk management together, while focusing on the compliance of the organisation with the sector's regulatory framework. The main similarities are: the regulatory strategic context of the organisation where the models were applied; the organisation purpose, that is to support the AM decision-making process in this matter; the multicriteria decision method used, that is the PROMETEE II; and the experts' knowledge, that is the basis for the analysis of the ISO requirements under the maturity (implementation of the ISO requirements) and relevance (the contribution of the ISO requirements to the sector's regulatory framework) criteria.

The main differences between the first and second models comprise respectively: the method approaches (which are the aggregation of the decision-makers' preferences and the aggregation of the experts' knowledge); the number of experts (4 and 14); the level of the decision of the sponsor in the organisation where the models were applied (middle level and high level); and the depth at which the regulatory requirements were considered (a general analysis and an in-depth analysis). It is important to highlight the fact that AM-RoM incorporates some of the topics suggested as a future research in the reviewed paper by Lima, de Lorena and Costa (2018), such as: an in-depth analysis of the regulatory framework, strategic guidelines, and the aggregation of the expert's knowledge in the decision-making modelling.

Particularly, regarding the AM-RoM, there are some points of improvement. One of them relates to the continuous scale, which varies from 0% to 100%, used for the assessment of the Compliance degree (Item 4.2.2) and the Implementation degree (Item 4.2.3). Another point of improvement is related to the use of the average to aggregate the results of the Integrated view of compliance degree and the Integrated view of Implementation degree.

Establishing ranges for the scale which is continuous and explaining the meaning of each range would certainly result in greater objectivity in the evaluation. Therefore, it would be expected that the responses of the evaluators would be less dispersed. Regarding the use of the average, a high coefficient of variation requires the study of an alternative form of aggregation

of the specialists' knowledge. When the variation is too significant, a possible solution could be the adoption of more appropriate strategies such as discussing with the professionals involved why the results are so dispersed and, afterwards, perform the evaluation process again. However, this is not always practical as it would be time-consuming and could make the research unfeasible. These suggestions, if implemented in future versions of the model, would certainly bring significant improvements in the quality of information and, consequently, in future results.

The ‘AM: Where to Start’ and ‘AM-RoM’ Models can be instantiated to the AM process of companies from various sectors of the economy. Because of the flexibility of the Models, it is possible to make a variety of adaptations to attend other necessities of organisations depending on the adopted strategy concept, such as culture, performance, decision-making process, and structure.

Regarding the use of the two models, the ‘AM: Where to Start Model’ is appropriate in situations where a detailed study of the regulatory framework is not required to proceed with the evaluations. In other words, a simplification which does not lose the efficiency of the support to decision making in the implementation of the AM process with a focus on regulation is sought for the organization. The second, AM-RoM, is a model that incorporates greater formality into the process, as it is based on the aggregation of the experts' knowledge. Also, this model supports decision-makers with a more appropriate treatment of information and provides richer results than the first model. It requires a deepening of the regulatory framework, therefore with a greater effort on the part of those involved.

The problem addressed by the two models fills a gap in the literature that links the theme regulation to the discipline of AM, in addition to considering relevant aspects of risk management. This is of interest to asset-intensive organisations that operate under the strong control of regulatory agencies. Both models contribute to the efforts of these organisations to comply with the regulations of the sector in which they operate. They were applied to a Brazilian company in the Energy Transmission Sector.

Regarding the third model, the AMBP offers insights to allow investment decisions in AM to be made by organisations with greater confidence, based on strategic performance indicators for the business. The Model identifies the relationship between AM – represented by key-processes, with the asset's value – measured by asset performance indicators (APIs), and with the business performance – measured by business key performance indicators (KPIs), which makes possible the support of business goals in a more targeted way. This contributes to organisations improving their performance and obtain better returns. It is extremely useful to

understand how AM affects business because investments in AM are significant, so it is possible to focus on ensuring that these investments in the AM processes are more relevant to the business context.

The AMPB Model was developed using data from AM case studies, regarding organisations from different sectors of the economy, such as health, transport, energy, agribusiness, among others, published in journals or websites specialized in AM. It minimizes a gap in the literature, with the main objective being to provide input for the understanding of 'how AM relates to business performance'. This is a fundamental and useful way to recognize other important issue, that is discovering ‘how the maturity of organisations in AM impacts the performance of the business’, an issue that remains up to date in the academic and business environments (LIMA; McMAHON; COSTA, 2020).

## 6.2 MAIN CONTRIBUTIONS OF THE THESIS

Asset Management, as discussed in the introduction to this thesis, is still a matter of great interest in both the academic and professional environments. The challenges faced by asset-intensive companies within the scope of the asset management theme are numerous. Particularly, the thesis offers problem-solving models to assist organisations in strategic contexts, such as compliance with regulation and improvement of business performance. It is possible to list the following main contributions:

(a) to fill a gap in the literature identifying priorities for the implementation of AM process whilst focusing on the regulatory framework of the Sector of the Economy.

(b) to promote the strategic alignment of the AM process with the business strategy, defining AM decision-making criteria compatible with the business objectives and integrating the various multifunctional areas of the organisation.

(c) to contribute to the improvement of business performance, providing a path to the understanding of the impact of AM on business.

(d) to meet the expectations of stakeholders, by adding value to the assets and encouraging an increase in the efficiency of decision-making in AM.

The research offers support and insights to the solution of real problems experienced by asset-intensive organisations, contributing to the efficiency of investments, to the valuation of assets, to better returns for the business and, in a more comprehensive view, for the economic aspect of the sectors of the economy as a whole.

By offering useful tools for asset-intensive organizations to make their decision-making processes more efficient when implementing or improving asset and risk management with a focus on regulation, a practical contribution to the sector's economy is made possible. This is because these organizations deal with highly significant investments. Therefore, more assertive decisions on investments in AM and RM, while seeking to meet regulatory requirements aiming at fair remuneration and mitigating possible fines, can promote a significant economic contribution. This can be perceived mainly in the AM Where to Start and AM-RoM models.

Also, an impressive contribution to state-of-the-art Asset Management is provided by the AM-BP Model. By offering a structured path aimed at increasing knowledge about how AM's key processes relate to key business indicators, the model offers a light in understanding how much AM may impact on the business. This brings a perspective of relevant future contribution to the performance of the country's infrastructure sector.

## 6.3 FUTURE WORKS

Although important contributions have been made, they do not end the research on Asset Management topic. There are still a variety of issues to be explored further, through future works. Some of them have been suggested in the referenced papers, and are reproduced below:

- To develop an Asset Management Maturity Model focusing on Regulation.
- To evaluate how the implementation of the ISO 55000: 2014 and ISO 31000: 2018 contributes to the organisation being more compliant, considering the hypothesis that the greater the degree of the structuring of the AM process, the greater the organisation’s compliance with the regulatory framework of the sector in which it operates.
- To discover if high-performance organisations have AM processes at an enhanced degree of maturity.
- To ascertain the reasons for a pattern of relationship between AM key-processes with business, depending on the sector of the economy.
- To design a model to measure the impact of the AM maturity on the business performance, based on the result of the application of the AMBP Model.

In addition to these future works, it is suggested to deepen the following AM topics:

- to broaden the focus of the AM-RoM with the incorporation of the requirements of the business performance strategy.

- to broaden the relationship between AM and business performance incorporating in the AMBP Model the relationship among the AM subjects themselves.

As can be seeing. Although AM is not a new issue as it is studied for more than thirty years, it is still challenging the organisations, mainly that ones that are asset-intensive organisations.

## REFERENCES

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS - AASHTO. **AASHTO transportation asset management guide: A focus on implementation**, 2011. Available on << https://store.transportation.org/Common/DownloadContentFiles?id=914 >>. Viewed on 17 May 2019.

AMADI-ECHENDU, J.; WILLETT, R.; BROWN, KERRY HOPE, T.; LEE, J.; MATHEW, J.; VYAS, N.; YANG, B. **What is engineering asset management?** Definitions, concepts and scope of engineering asset management. London: Springer, p. 3-16, 2010.

AMBEC, S.; COHEN, Mark A.; ELGIE, Stewart; LANOIE, Paul. The Porter hypothesis at 20: can environmental regulation enhance innovation and competitiveness? **Review of Environmental Economics and Policy**, v. 7, n. 1, p. 2-22, 2013.

ASSET MANAGEMENT COUNCIL - AMC. **Asset Management Body of Knowledge (AMBoK):** Framework for Asset Management. 2. ed. Melbourne, Australia: AMC, 2014.

ANDRES, Terry. Sensitivity Analysis. In NEIL, J. **Encyclopedia of research design**. vol 1. Lawrence: University of Kansas, 2010.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL (2011). **Resolução Normativa ANEEL nº 443 de 26/07/2011**. Available on << https://biblioteca.aneel.gov.br/asp/textos_main.asp?codigo=120243&desc=ti&servidor=1&iBanner=&iIdioma=0 >>. Viewed on 30 November 2020.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL (2018a). **Bem-vindo à ANEEL!** Available on << http://www.aneel.gov.br/a-aneel >> Viewed on 20 May 2019.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL (2018b)**. Regulação econômica do segmento de Transmissão**. Available on << http://www.aneel.gov.br/regulacao-economica-de-transmissao >>. Viewed on 20 May 2019.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL (2018c)**. Superintendência de Regulação Econômica e Estudos do Mercado – SEM**. Available on << https://www.aneel.gov.br/srm >>. Viewed on 20 May 2019.

ASSETIVITY (2015a). **Asset management audit strategy development and implementation.** Available on << https://www.assetivity.com.au/images/CBH_Case_Study_small.pdf >>. Viewed on 03 April 2019.

ASSETIVITY (2015b). **Maintenance & operating cost estimation development.** Available on << https://www.assetivity.com.au/images/MOCED_Case_Study_Final.pdf >> Viewed on 03 April 2019.

ASSETIVITY (2015c)**. Maintenance & reliability improvement program with Panaust.** Available on << https://www.assetivity.com.au/images/PanAust_Case_Study_Final.pdf >>. Viewed on 03 April 2019.

ASSETIVITY (2015d). **Western Power Case Study Conductor Strategy Review.** Available on << https://www.assetivity.com.au/images/PDF/Case_Studies/Western_Power_Case_Study_Conductor_Strategy_Review.pdf. Viewed on May 2019 >>. Viewed on 03 April 2019.

ASSETIVITY (2016a). **Asset Integrity Assessment.** Available on << https://www.assetivity.com.au/images/Asset_Integrity_Assessment.pdf >>. Viewed on 05 April 2019.

ASSETIVITY (2016b). **Asset management training**. Available on << https://www.assetivity.com.au/images/ISO_55001_Asset_Management_Training_Case_Study.pdf >>. Viewed on 05 April 2019.

ASSETIVITY (2016c). **ISO 55001 Gap Assessment Case Study**. Available on << https://www.assetivity.com.au/images/ISO_55001_Gap_Assessment_Case_Study.pdf >>. Viewed on 05 April 2019.

ASSETIVITY (2016d). **Operational readiness support with Santos**. Available on << https://www.assetivity.com.au/images/Santos_Operational_Readiness_Case_Study.pdf >>. Viewed on 05 April 2019.

ASSETIVITY (2018). **Asset management accountability framework (amaf) gap assessment.** Available on << https://www.assetivity.com.au/images/PDF/Case_Studies/Royal_Womens_Hospital_AMAF_Rev2.pdf >>. Viewed on 05 April 2019.

ATTWATER, A.; WANG, J. Q.; PARLIKAD, A.; RUSSELL, P. **Measuring the performance of asset management systems (2014).** Available on << https://www.researchgate.net/publication/266768867_Measuring_the_performance_of_asset_management_systems >>. Viewed on 16 May 2019.

AVEN T.; RENN O. Improving government policy on risk: Eight key principles in **Reliability Engineering and System Safety**, 2018;176:230–41.

BIRKINSHAW, J.; GODDARD, J. **What's is your management model?** MIT Sloan Management Review, 2009. v. 50. Available on << https://sloanreview.mit.edu/article/what-is-your-management-model/ >>. Viewed on 18 May 2019.

BUREAU OF INFRASTRUCTURE TRANSPORT AND REGIONAL ECONOMICS – BITRE. **Measuring infrastructure asset performance and customer satisfaction: a review of existing frameworks**. Canberra: ACT, 2017

BLANCHARD, B. S.; BLYLER, J. E. Introduction in **System Engineering Management**. USA: John Wiley & Sons Inc, 2016.

BRANS, J. P.; VINCKE, P. H. A preference ranking organization method, the PROMETHEE method for MCDM. **Management Science**, v. 31, p. 647-656, 1985.

BRANS, J. P.; de SMET, Y. *PROMETHEE methods*. Int Ser Oper Res Manag Sci 2016;233:187–219.

BRANS, J. P.; VINCKE, P. H.; MARESCHAL, B. How to select and how to rank projects: The PROMETHEE method. **European journal of Operational Research**, North-Holland, Volume 24, Issue 2, February, p. 228-238, 1986.

BROWN, R. E.; SPARE, J. H. Asset management, risk and distribution system planning in **IEEE PES power systems conference & exposition**, New York, 10-13 October 2004.

BROUS, P.; JANSSEN, M.; HERDER, P. Coordinating Data-Driven Decision-Making in **Public Asset Management Organizations:** A Quasi-Experiment for Assessing the Impact of Data Governance on Asset Management Decision Making, 2016. IFIP International Federation for Information Processing 2016. Y.K. Dwivedi et al. (Eds.): I3E 2016, LNCS 9844, p. 573–583, 2016.

BURNETT, S.; VLOK, P.J. A Simplified Numerical Decision-Making Methodology for Physical Asset Management Decisions in **The South African Journal of Industrial Engineering**, v. 25, n. 1, 2014.

BRUNETTO, Y; XERRI, M; NELSON, S. Building a Proactive, Engagement Culture in Asset Management Organizations in **Journal of Management in Engineering**, v. 30, n. 4, 2014.

CATRINU, M. D.; NORDGÅRD, D. E. Integrating risk analysis and multi-criteria decision support under uncertainty in electricity distribution system asset management in **Reliability Engineering and System Safety**, p. 663–70, 2011.

CAVALCANTE, C. A. V.; SCARF, P. A.; BERRADE, M. D. Imperfect Inspection of a System with Unrevealed Failure and an Unrevealed Defective State in **IEEE Transactions on Reliability**, v. 68, p. 764-775, 2019.

CAVKA, H. B.; STAUB-FRENCH, S.; POIRIER, E. A. Developing owner information requirements for BIM-enabled project delivery and asset management in **Automation in Construction**, v. 83, p. 169-183, 2017.

CHANDIMA RATNAYAKE, R. M.; MARKESET, T. Asset integrity management for sustainable industrial operations: measuring the performance in **International Journal of Sustainable Engineering**, v. 5, n. 2, p. 145-158, 2012.

CHAREONSUK, C; CHANSA-NGAVEJ, C. Intangible asset management framework for long-term financial performance in **Industrial Management & Data Systems**, v. 108, n. 6, p. 812-828, 2008.

CHEMWENO, P.; PINTELON, L.; VAN HORENBEEK, A. Asset maintenance maturity model as a structured guide to maintenance process maturity in **Maintenance and Performance Measurement MPMM**. Finland: Lappeenrants, 2013.

CHIRUMALLA, K. BERTONI, A; ADITYA, P; JOHANSSON, C. Performance Measurement Framework for Product-Service System Development: A Balanced Scorecard Approach in **International Journal of Technology Intelligence and Planning (IJTIP)**, v. 9, n. 2, p. 146-164, 2013.

CHOO, B. S. Y. Pragmatic adaptation of the ISO 31000: 2009 enterprise risk management framework in a high-Tech organization using Six Sigma in **International Journal of Accounting & Information Management**, v 23, p. 364–82, 2015.

DASHTI R.; YOUSEFI, S. Reliability based asset assessment in electrical distribution systems in **Reliability Engineering and System Safety**, p. 112-129, 2013.

DAVIS, R. **An Introduction to Asset Management.** (2001-?) [online] Available on << http://www.hvds.co.nz/files/docs/10695_iam_beginners_guide_low_9.pdf >>. Viewed on 14 October 2020.

de ALMEIDA, A.T; MORAIS COSTA, A. P.; ALENCAR, L.; DAHER, S. **Decisão em Grupo e Negociação:** métodos e aplicações. São Paulo: Atlas, 2012.

de ALMEIDA A. T.; CAVALCANTE, C. A. V; ALENCAR, M. H. **Multicriteria and Multiobjective Models for Risk, Reliability and Maintenance Decision Analysis.** vol. 231. Berlim: Springer, 2015.

DENNIS, M.; RAMASWAMY, C.; AMEEN, M. N.; JAYARAM, V. (2017) **Asset Performance Management Maturity Model.** Available on << https://www.capgemini.com/wp-content/uploads/2017/08/asset_performance_management_maturity_model_paper_web_version.pdf >>. Viewed on 19 May 2019.

DUNN, S. (2015). **Visualising the International Asset Management Standard ISO 55001**. 1 vídeo (18:33 min.). Available on << https://www.assetivity.com.au/article/asset-management/visualising-iso-55001.html >>. Viewed on 13 October 2020.

DWIGHT, R.; El-AKRUTI, K. O. **The role of asset management in enterprise strategy success.** Available on << https://ro.uow.edu.au/cgi/viewcontent.cgi?article=7947&context=engpapers >>. Viewed on 25 May 2019.

DWIGHT, R.; ZHANG, T.; El-AKRUTI, K. O. Asset management in the energy pipeline industry in Australia in **Trends in Maintenance Engineering** (M-Tech 2013), p. 1-10, 2013.

ECKERSON, W. W. **Performance Dashboards** - Measuring, Monitoring, and Managing Your Business. 2 ed. USA: John Wiley & Sons, 2010, p.23.

EDMONDSON, A. C. The competitive imperative of learning in **Harvard Business Review**, July-August. p. 60-67. 2008.

El-AKRUTI, K.; DWIGHT, R. A framework for the engineering asset management system in **Journal of Quality in Maintenance Engineering**, v. 19, n. 4, p. 398-412, 2013.

El-AKRUTI, K.; DWIGHT, R.; ZHANG, T., The strategic role of engineering asset management in **International Journal of Production Economics**, v. 146, n. 1, p. 227-239, 2013.

ENERGEX. **Energex -** Asset Management Strategy Energex. Brisbane: QLD, 2014.

NAKANO, Davi. Métodos de Pesquisa Adotados na Engenharia de Produção e Gestão de Operações in CAUCHICK, M. P. A. (coord) et al. **Metodologia de pesquisa em engenharia de produção e gestão de operações**. 2ª ed. São Paulo: Elsevier, 2012.

FROLOV, V.; MEGEL, D.; BANDARA W.; SUN Y. Building an ontology and process architecture for engineering asset management in KIRITSIS, D.; EMMANOUILIDIS, C.; KORONIOS, A.; MATHEW, J. **Engineering Asset Lifecycle Management.** Proceedings of the 4thWorld Congress on Engineering Asset Management (WCEAM 2009). 28-30, September 2009.

GLOBAL FORUM ON MAINTENANCE E ASSET MANAGEMENT - GFMAM (2014). **The Asset Management Landscape**. Second Edition. Available on << http://www.gfmam.org.>> Viewed on 8 March 2019.

GLOBAL FORUM ON MAINTENANCE E ASSET MANAGEMENT - GFMAM (2015). **Asset Management Maturity A Position Statement.** Available on << www.gfmam.org >>. Viewed on 8 May 2018.

GLOBAL FORUM ON MAINTENANCE E ASSET MANAGEMENT - GFMAM (2016). **The Value of Asset Management to an Organisation**. First Edition. English Version. Available on << https://gfmam.org/sites/default/files/2019-05/GFMAM_THE_MAINTENANCE_FRAMEWORK_FIRST_EDITION_ENGLISH_VERSION.pdf >>. Viewed on 8 May 2018.

GODAU, R. Why asset management should be a corporate function in **Journal of Public Works & Infrastructure**, v. 1, n. 2, p. 171-184, 2008.

GODAU, R.; McGEOCH, M. ISO 55001 Ready–Focus on improving Asset Management Maturity in **AMPEAK Asset Management Conference**, Adelaide, Australia, 10-13, April 2016.

GOV UK (2014). **Government Property Profession and Cabinet Office.** Available on <<https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/394996/PAMCAM-Question-Set-FINAL-July-2014-v1.1.pdf.>> Viewed on 10 October 2020.

GREEMAN, S (2019). **Optimized asset management decision-making:** Asset management decision-making, the pathway to value. Available on << https://greemanassetmanagement.com/optimized-asset-management-decision-making/ >>. Viewed on 10 October 2020.

HAIDER, A. IT Enabled Engineering Asset Management: A Governance Perspective in **Journal of Organizational Knowledge Management**, Vol. 2011. IBIMA Publishing, 2011.

HAMMER, M. Deep Change: how operational innovation can transform your company in **Harvard Business Review**, v. 82, n. 4, 2004.

HARRIS, H.; CARAPIET, S. The Need for Agility in **Asset Management.** London, UK: Springer. 2006.

HEALTHCARE FINANCIAL MANAGEMENT ASSOCIATION - HFMA (2013). **Optimizing Asset Management for Strategic Agility.** vol 67, issue 8, special section, p1-8, 2013.

HOOKE, O. Macroeconomic aspects of competitiveness in **Baltic Journal of Economic Studies**, v. 3, n. 4, 2017.

HOSSAIN, M. Asset management beyond roads in **Cairns International Public Works Conference**. Cairns, Queensland, Australia, August 2007.

INSTITUTE OF ASSET MANAGEMENT - IAM (2015). **Asset Management** – an anatomy. Version 3, 2015.

INSTITUTE OF ASSET MANAGEMENT - IAM (2016). **Asset Management Maturity Scale and Guidance**. Version 1.1, 2016.

INSTITUTE OF ASSET MANAGEMENT - IAM; BRITISH STANDARDS INSTITUTION - BSI (2008a). **PAS 55-1:** 2008 Asset management, part 1: Specification for the optimized management of physical assets, Institute for Asset Management and British Standard Institution: Bristol, United Kingdom, 2008.

INSTITUTE OF ASSET MANAGEMENT - IAM; BRITISH STANDARDS INSTITUTION - BSI (2008b). **PAS 55-2:** 2008 Asset management, part 2: Guidelines for the application of PAS 55- 1, Institute for Asset Management and British Standard Institution: Bristol, United Kingdom, 2008.

INTERNATIONAL COPPER ASSOCIATION – ICA (2015). **Gestão de Ativos Guia para aplicação da Norma ABNT NBR ISO 55001**. Latin America, p. 88, 2015.

ILORI, O. O. Extent of Use of Continuous Improvement Process in Engineering Asset Management Practices in Oil and Gas Service Industry in Nigeria in **Australian Journal of Multi-Disciplinary Engineering**, v. 11, n. 2, p. 157-164, 2015.

ISHAQ BHATTI, M.; AWAN, H. M.; RAZAQ, Z. The key performance indicators (KPIs) and their impact on overall organizational performance in **Quality & Quantity**, v. 48, n. 6, p. 3127-3143, 2013.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2009). **Guide 73:** Risk Management – Vocabulary. Geneva, 2009.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2014a). **ISO 55000:** 2014 - Asset management - Overview, principles and terminology. Geneva, 2014.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2014b). **ISO 55001:** 2014 - Asset management — Management systems — Requirements. Geneva, 2014.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2014c). **ISO 55002:** *2014* - Asset management — Management systems — Guidelines for the application of ISO 55001. Geneva, 2014.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2015a). **ISO 9001:** *2015* - Quality Management System. Geneva, 2015.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2015b). **ISO 14001:** 2015 - Environmental Management System. Geneva, 2015.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2018). **ISO 31000:** 2018 - Risk Management – Guidelines. Geneva, 2018.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION - ISO (2019). **ISO 55010:** 2019 - Asset management — Guidance on the alignment of financial and non-financial functions in asset management. Geneva, 2019.

JAMER, M (2019). **Case study:** asset management in the city of Fredericton. Available on << https://publicsectordigest.com/article/case-study-asset-management-in-city-fredericton-0 >>. Viewed on 18 May 2019.

KEENEY, R. L. **Value-Focused Thinking:** A Path to Creative Decisionmaking. Harvard, Cambridge: Harvard University Press, 1992.

KELLY, J.; HARDY, M. Asset Management In high performance organisation Whitepaper in **Asset Leadership Network**, 2018.

KERSLEY, T.; SHARP, A. J. The asset management journey: A case study of network rail's journey supported by an excellence model in **Asset Management Conference 2014**, London, UK., 27-28 November 2014.

KEYSER, W.; PEETERS, P. Theory and Methodology: A note on the use of PROMETHEE multicriteria methods in **European Journal of Operational Research**, Volume 89, Issue 3, 22 March, Pages 457-461, 1996.

KHALIQ, S. A.; MAHMOOD, M.N.; DAS, N. Towards a best practice asset management framework for electrical power distribution organisations in **IEEE PES Asia-Pacific Power and Energy Engineering Conference**, 2015.

KHUNTIA, S. R. et al. A literature survey on asset management in electrical power [transmission and distribution] system in **International Transactions on Electrical Energy Systems**, v. 26, n. 10, p. 2123-2133, 2016.

KOOP, C.; LODGE, M. What is regulation? An interdisciplinary concept analysis in **Regul Gov**, V.11, p. 95–108, 2017.

LAUE, M. BROWN, K.; SCHERRER, P.; KEAST, P. **Integrated strategic asset management:** frameworks and dimensions. Berlim: Springer, 2014.

LIMA, E. S.; COSTA, A. P. C. S. Improving Asset Management under a regulatory view in **Reliability Engineering and System Safety**, v. 190, 2019.

LIMA, E. S. ; LORENA, A. L. F. ; COSTA . Structuring the Asset Management based on ISO 55001 and ISO 31000: Where to start? in **2018 IEEE International Conference on Systems, Man, and Cybernetics, 2018.** Miyazaki, 2018.

LIMA, E. S.; McMAHON, P.; COSTA, A. P. C. S. *Establishing the relationship between asset management and business performance* in **International Journal of Production Economics.** Volume 232, February 2021.

LIN, S. GAO, J.; KORONIOS, A.; CHANANA, V. Developing a data quality framework for asset management in engineering organisations in **International Journal of Information Quality**, v.1, p. 100, 2007.

LOPES, R. S.; CAVALCANTE, C. A. V. Multi-criteria model to support the definition of opportunistic maintenance policy: A study in a cogeneration system in **Energy** (Oxford), v. 80, p. 32-40, 2015.

LUSTHAUS, C.; CARDEN, F.; ADRIEN, M. H.; ANDERSON, G.; MONTALVÁN, G. P. **Organizational Assessment:** A framework for improving performance. DC: Inter-American Development Bank, 2002.

LUTHANS, K. Recognition: A Powerful, but often Overlooked, Leadership Tool to Improve Employee Performance in **Journal of Leadership Studies**, v. 7, n. 1, p. 31-39, 2016.

MA, Z.; ZHOU, L.; SHENG, W. Analysis of the new asset management standard ISO 55000 and PAS 55 in **IEEE 2014 China International Conference on Electricity Distribution (CICED), Shenzhen**, China, 23–26 September 2014.

MARSARO, M. F.; CAVALCANTE, C. A. V. Random preventive maintenance policy based on inspection for a multicomponent system using simulation in **Eksploatacja i Niezawodnosc-Maintenance and Reliability**, v. 19, p. 552-559, 2017.

MAHMOOD, M. N.; DHAKAL, S. P.; WIEWIORA, A.; KEAST, R. L. A comparative study on asset management capability maturity models in **International Journal of Strategic Engineering Asset Management**, v. 2, n. 4, p. 328-347, 2015.

MALETIČ, M; AL-NAJJAR, B.; GOMIŠČEK, B. Development of a Model Linking Physical Asset Management to Sustainability Performance: An Empirical Research in **Sustainability**, 2018, vol. 10, no. 12, doi:10.3390/su10124759.

MEHAIRJAN, R. P.; FANTANA, N. L.; SMIT, J. J. Information and Risk-based Strategies for Lifetime Asset Management in **CIGRE Symposium B3**, Nagoya, Japan. 2016.

MEHAIRJAN, R. P. Y. Organisational Wide Maintenance Improvement Framework in **Risk-Based Maintenance for Electricity Network Organizations**. Berlim: Springer International Publishing. 2017.

MEIER, H.; LAGEMANN, H.; MORLOCK, F.; RATHMANN, C. Key Performance Indicators for Assessing the Planning and Delivery of Industrial Services in **Procedia CIRP**, v. 11, p. 99-104, 2013.

MILINA, J.; KRISTIANSEN, P.; SUNDVE, A. I. Molding the asset management system to pas 55-1/ISO 55001 in one Scandinavian water and wastewater works in **Water Pract Technol,** vol 12, p. 234–9, 2017.

MORIN, E; AUDEBRAND, L. K. Organizational performance and the meaning of work: correcting for restricted range in **International Conference of the Iberoamerican Academy of Management**, São Paulo, Brazil. 2003.

MOUZAS, S. Efficiency versus effectiveness in business networks in **Journal of Business Research**, vol. 59, no. 10-11, p. 1124-1132. 2006.

MURALI, K. G (2017). Keep it simple, sensible Asset Management. Available on << https://www.ipwea.org/communities/assetmanagement/consultantcasestudies >>. Viewed on 20th May 2019.

NAKANO, D. Métodos de Pesquisa Adotados na Engenharia de Produção e Gestão de Operações (capítulo 4) in MIGUEL, P. A. C. (Ed). **Metodologia de Pesquisa em Engenharia de Produção e Gestão de Operações.** Rio de Janeiro: Elsevier, 2012.

NALLAPERUMAL, K (2013). **Engineering Research Methodology:** A Computer Science and Engineering and Information and Communication Technologies Perspective. First Edition Book, Available on << https://edisciplinas.usp.br/pluginfile.php/4125670/mod_resource/content/1/engineering_research_methodology.pdf >>. Viewed on 30 June 2020.

NEIJENS, B. Improving asset utilization with an asset investment planning and management methodology in **Water Pract Technol.** V. 2, p. 43–7, p. 2017.

NEL, C. B. H.; JOOSTE, J. L. A Technologically-Driven Asset Management Approach to Managing Physical Assets - a Literature Review and Research Agenda for 'Smart' Asset Management in **South African Journal of Industrial Engineering**, v. 27, n. 4, p. 50-65, 2016.

NETWORK RAIL. **Asset Management Strategy**. London, UK: Network Rail, 2014.

PARIDA, A. Maintenance performance assessment (MPA) framework for engineering asset in **IEEE International Conference on Industrial Engineering and Engineering Management**, 2008.

PARIDA, A. **Asset performance assessment**. 7 ed. Dordrecht: Springer, 2012.

PARIDA, A. Asset performance measurement and management: Bridging the gap between failure and success. Measurement in **EuroMAINTENANCE**, Athens, Greece, 2016.

PARIDA, A.; CHATTOPADHYAY, G. Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM) in **Journal of Quality in Maintenance Engineering**, v. 13, n. 3, p. 241-258, 2007.

PARIDA, A.; GALAR, D.; KUMAR, U.; STENSTRÖM, C. Performance measurement and management for maintenance: a literature review in **Journal of Quality in Maintenance Engineering**, v. 21, n. 1, p. 2-33, 2015.

PETCHROMPO S.; PARLIKAD, A. K. A review of asset management literature on multi-asset systems in **Reliability Engineering and System Safety**. vol. 181, p. 181–201, 2019.

POLENGHI A.; MACCHI, M.; RODA, I.; POZZETTI, A. Conceptual Framework for a Data Model to Support Asset Management Decision-Making Process in AMERI F., STECKE K., VON CIEMINSKI G., KIRITSIS D. (eds) **Advances in Production Management Systems:** Production Management for the Factory of the Future. APMS 2019. IFIP Advances in Information and Communication Technology, vol 566. Cham: Springer, 2019.

PRAGALE, R.; PATEL, A.; BRESDEN, R. ARC. Flash KPI Compliance at a Large Oil and Gas Company in **IEEE Transactions on Industry Applications**, v. 54, n. 1, p. 889-894, 2018.

PRESTON, C. C.; COLMAN, A. M. Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences in **Acta Psychologica**, p. 1–15, 2000.

RASTEGARI, A.; SALONEN, A. Strategic maintenance management: Formulating maintenance strategy in **International journal of COMADEM**, v. 18, n. 1, p. 5-14, 2015.

RISA, E.; LIYANAGE, J. P. On the Capitalization and Management of Infrastructure Assets: A Case from the North Sea on Its Natural Gas Export Pipelines in **Engineering Asset Management-Systems, Professional Practices and Certification**. Cham: Springer, 2015. p. 495-507.

RODA, I.; MACCHI, M. Studying the funding principles for integrating Asset Management in Operations: an empirical research in production companies in **International Federation of Automatic Control - IFAC**, Sherbrooke, Quebec, Canada, p. 21-25, August 2016.

SABEI, D.; ERKOYUNCU, J.; ROY, R., A review of Multi-criteria decision methods for enhanced maintenance delivery in **Procedia CIRP**, v. 37, p. 30-35, 2015.

SCHNEIDER, J. NEUMANN, C.; GAUL, A. J.; HOGRÄFER, J. Asset management techniques in **Int J Electr Power Energy Syst**. v 28, p. 643–54, 2006.

SCHUMAN, C.A.; BRENT, A. C. Asset life cycle management: towards improving physical asset performance in the process industry in **International Journal of Operations & Production Management**, v. 25, n. 6, p. 566-579, 2005.

SHAH, R.; McMANN, O.; BORTHWICK, F. Challenges and prospects of applying asset management principles to highway maintenance: A case study of the UK in **Transportation Research Part A:** Policy and Practice, v. 97, p. 231-243, 2017.

SHAMSAEI, A.; AMYOT, D.; POURSHAHID, A. A systematic review of compliance measurement based on goals and indicators in **International Conference on Advanced Information Systems Engineering**, London, United Kingdom, 20-24 June 2011.

SEPP NEVES, A. A.; PINARDI, N.; MARTINS, F.; JANEIRO, J.; SAMARAS, A.; ZODIATIS, G.; DE DOMINICIS, M. Towards a common oil spill risk assessment framework - Adapting ISO 31000 and addressing uncertainties in **J Environ Manage.** v 159, p. 158–68, 2015.

SILVA, V. B. S.; MORAIS, D. C.; de ALMEIDA, A. T. A Multicriteria Group Decision Model to Support Watershed Committees in Brazil in **Water Resources Management**, Springer, V. 24, 14. ed., p. 4075-4091, 2010.

SRIMAI, S.; RADFORD, J.; WRIGHT, C. Evolutionary paths of performance measurement in **International Journal of Productivity and Performance Management**, v. 60, n. 7, p. 662-687, 2011.

SRINIVASAN, R.; PARLIKAD, A. K. An approach to value-based infrastructure asset management in **Infrastructure Asset Management**, v. 4, n. 3, p. 87-95, 2017.

SUN, Y.; FIDGE, C.; MA, L. A generic split process model for asset management decision-making in **Proceedings of the 3rd World Congress on Engineering Asset Management and Intelligent Maintenance Systems**, China, Beijing, 2008.

SYVERSON, C. What Determines Productivity? in **Journal of Economic Literature**, v. 49, n. 2, p. 326-365, 2011.

TAM, S. B.; PRICE, J. W. Optimisation framework for asset maintenance investment. **Monash Business Review**, v. 2, n. 3, p. 1-10, 2006.

TESSEMA, M. T.; READY, K. J.; EMBAYE, A. B. The effects of employee recognition, pay, and benefits on job satisfaction: cross country evidence in **Journal of Business and Economics**, v. 4, n. 1, p. 1-12, 2013.

TRINDADE, M. et al. Design and Development of a Value-Based Decision Making Process for Asset Intensive Organizations in **Asset Intelligence through Integration and Interoperability and Contemporary Vibration Engineering Technologies**. Berlim: Springer, 2019.

TOO, E. G. A framework for strategic infrastructure asset management in **3rd World Congress on Engineering Asset Management and Intelligent Maintenance Systems Conference (WCEAM-IMS 2008):** Engineering Asset Management – A Foundation for Sustainable Development, Beijing, China, 27 – 30 October 2008.

TOO, E. G.; TOO, L. Strategic infrastructure asset management: a conceptual framework to identify capabilities in **Journal of Corporate Real Estate**, v. 12, n. 3, p. 196-208, 2010.

VOLKER, L; VAN der LEI, T. E.; LIGTVOET, A. Developing a maturity model for infrastructural asset management systems in **10th Conference on Applied Infrastructure Research –** Infraday, 7-8 October, Berlin, Germany, 2011.

VOLKER, L. et al. Asset management maturity in public infrastructure: the case of Rijkswaterstaat in **International Journal of Strategic Engineering Asset Management**. v. 1, n. 4, 2013.

WOODHOUSE, J. Physical Asset Management in DARLING, P. (ed.). **SME Mining Engineering Handbook**. London, UK, 2011.

WOODHOUSE, J. 'What is the value of asset management?' in **Infrastructure Asset Management**, v. 6, n. 2, p. 102-108, 2018.

ZEB, J.; FROESE, T.; VANIER, D. Infrastructure Management Process Maturity Model: Development and Testing in **Journal of Sustainable Development**, v. 6, n. 11, 2013.

ZUASHKIANI, A.; RAHMANDAD, H.; JARDINE, A. K. S. Mapping the dynamics of overall equipment effectiveness to enhance asset management practices in **Journal of Quality in Maintenance Engineering**, v. 17, n. 1, p. 74-92, 2011.