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IMPROVING ASSET MANAGEMENT MATURITY IN PRODUCTION SYSTEM: A NOVEL DSS TO MATURITY ASSESSMENT AND EVIDENCE ON BUSINESS PERFORMANCE

GABRIEL HERMINIO DE ANDRADE LIMA

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2025

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IMPROVING ASSET MANAGEMENT MATURITY: A NOVEL DSS TO MATURITY ASSESSMENT AND EVIDENCE ON BUSINESS PERFORMANCE

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: Profª. Drª. Ana Paula Cabral Seixas Costa

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ABSTRACT

Asset management (AM) has emerged as an interdisciplinary approach that enables the improvement of the financial and non-financial value delivery of assets in asset-intensive organizations. However, many organizations have conveyed challenges in the AM implementations and decision-making processes, which may come from the absence of tools and managerial capabilities. In order to support the improvement of AM processes, asset management maturity models (AMMMs) have been developed in academia and practice, which face some difficulties. Specifically, the AM literature reports that these AMMMs have not developed an assessment procedure and have not provided evidence to the validation process, provoking challenges in the application that may reduce the effectiveness of the assessment. Therefore, although there are AMMMs available, a novel AMMM needs to be developed to overcome these challenges. Then, by applying design science research, a reference model and the Asset Management Maturity Assessment Procedure (AMAP) were developed, which are implemented in a decision support system (DSS) to guarantee replicability and a self-assessment approach. On the other hand, another interesting challenge has stood out in the AM literature: the relationship between AM maturity and business performance. Considering this, data from AMAP applications were modeled using Partial least squares structural equation modeling in order to reveal the role of AM maturity on business performance, which demonstrates a positive association. Therefore, the thesis proposes a tool for asset-intensive organizations to assess their AM maturity, enabling the development of roadmaps for improvement, as well as bringing empirical evidence of the impact of AM maturity on business performance.

Keywords: Asset Management; Asset Management Maturity Model; Decision Support System; Business Performance; PLS-SEM.

RESUMO

A gestão de ativos (GA) surgiu como uma abordagem interdisciplinar que permite a melhoria da entrega de valor financeiro e não financeiro dos ativos em organizações intensivas em ativos. No entanto, muitas organizações têm enfrentado desafios nas implementações de GA e nos processos de tomada de decisão, que podem advir da ausência de ferramentas e capacidades gerenciais. Para apoiar a melhoria dos processos de GA, modelos de maturidade em gestão de ativos (AMMMs) foram desenvolvidos na academia e na prática, os quais enfrentam algumas dificuldades na fase de aplicação. Especificamente, a literatura sobre GA relata que esses AMMMs não desenvolveram um procedimento de avaliação e não forneceram evidências para o processo de validação, provocando desafios na aplicação que podem reduzir a eficácia da avaliação. Portanto, embora existam AMMMs disponíveis, um novo AMMM precisa ser desenvolvido para superar esses desafios. Em seguida, aplicando *design Science research* foram desenvolvidos um modelo de referência e o Procedimento de Avaliação da Maturidade em Gestão de Ativos (AMAP), que são implementados em um sistema de suporte à decisão (DSS) para garantir a replicabilidade e uma abordagem de autoavaliação. Por outro lado, outro desafio interessante se destacou na literatura de AM: a relação entre a maturidade em GA e o desempenho empresarial. Considerando isso, os dados de aplicações no AMAP para a performance do negócio foram modelados usando a equação de modelagem estrutural de mínimos quadrados parciais para revelar o papel da maturidade em GA no desempenho empresarial, o que demonstra uma associação positiva. Portanto, a tese propõe uma ferramenta para organizações intensivas em ativos avaliarem sua maturidade em GA, permitindo o desenvolvimento de caminhos para melhoria, bem como trazendo evidências empíricas do impacto da maturidade em AM no desempenho empresarial.

Palavras-chaves: Gestão de Ativos; Modelo de Maturidade em Gestão de Ativos; Sistema de Suporte à Decisão; Desempenho Empresarial; PLS-SEM.

FIGURE LIST

TABLE LIST

Table 29 – Path coefficients linked to Leadership & People competence and the control variables

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1 INTRODUCTION

Physical assets are organizational resources that contribute to delivering value for the business (IAM, 2024; ISO, 2024a). In this sense, operating assets enable organizations to realize business value, as assets carry both actual and potential value to be delivered (AMADI-ECHENDU, 2004). Due to these aspects, the scientific production related to asset management (AM) has increased (JUNG; KIM, 2021; SANDU; VARGANOVA; SAMII, 2023).

AM is an interdisciplinary approach that aggregates activities to manage assets, while balancing cost, performance, and risk, in order to achieve organizational objectives (EL-AKRUTI; DWIGHT; ZHANG, 2013; IAM, 2024; ISO, 2024a; KOMONEN; KORTELAINEN; RÄIKKÖNEN, 2012). Considering this definition, asset-intensive organizations use AM to manage the asset lifecycle, which comes from the identification of needs for assets to the disposal of assets (SCHUMAN; BRENT, 2005).

In this context, asset-intensive organizations can be characterized by multiple assets with a long lifespan, which operate networked manner, so that their failure can bring down the production system (WIJNIA, Y.; DE CROON; LIYANAGE, 2014). Then, assets are critical for operation, making them strategic elements for the organization (PARIDA, 2012; SCHUMAN; BRENT, 2005). Therefore, asset-intensive organizations, such as industry, manufacturing, infrastructure, and transportation, have a strong dependence on their asset system.

In deepening the analysis of the organizational relevance of assets, GFMAM, (2024) highlights that assets are not only organizational resources but also vehicles for generating value for stakeholders. Consequently, the activities of AM must consider the holistic perspective of their stakeholders (GAVRIKOVA; VOLKOVA; BURDA, 2020; GFMAM, 2024; PETCHROMPO; PARLIKAD, 2019). Therefore, AM enables organizations to develop programs that bring the maximum contribution of assets.

As a result, organizations need to measure the performance of their assets and AM processes, which must be a holistic perspective (PARIDA, 2012; PARIDA; CHATTOPADHYAY, 2007). Although the measurement process is complex in the AM context due to the interaction in the asset systems and the asset's long lifespan (EL-AKRUTI; KIRIDENA; DWIGHT, 2018), it is possible to highlight many AM benefits.

As mentioned, the main contribution of AM is to realize value from assets (IAM, 2024; SRINIVASAN; PARLIKAD, 2020). Additionally, AM contributes to financial and non-financial aspects, encompassing sustainability, employee satisfaction, mitigation of risk, and

other benefits (ISO, 2024a). However, most of these contributions are validated based on case studies on practices, then few papers have sought to validate empirically. In this context, HAN et al., (2021) and MALETIČ et al., (2020) find evidence that AM practices influence operational performance. Then, it emerges the demand to assess the effectiveness of AM.

Despite these benefits, some challenges are highlighted in AM literature. For example, many AM decisions are based on intuition (KOMONEN; KORTELAINEN; RÄIKKÖNEN, 2012; VAN RIEL *et al.*, 2014) that is collaborated with the absence of data, interoperability, and lack of skills (DAULAT *et al.*, 2024; PARLIKAD, A.K.; JAFARI, 2016; SHAH; MCMANN; BORTHWICK, 2017). Most of these challenges can be addressed by the development of AM processes. In light of this, GFMAM, (2024) identify forty AM dimensions that are common in AM routine.

These challenges, mainly related to data management, complicate the assessment of AM practices, which require the measurement of performance indicators (PARIDA, 2012; PARIDA *et al.*, 2015). Then, the effectiveness of AM practices needs to be investigated using new approaches. Taking into account that processes support the delivery of value for stakeholders and the organization (HAMMER, 2015), measuring AM processes can be a means to infer to delivery value of AM.

Among the methodologies for measuring business processes, Maturity Models (MMs) stand out for promoting the learning process and continuous improvement (BITITCI, UMIT S. *et al.*, 2015). MMs are managerial tools that allow for assessing business processes, enabling the organization to design roadmaps to improve the effectiveness of organizational capability (BECKER; KNACKSTEDT; PÖPPELBUSS, 2009; LEE, DONGHUN; GU; JUNG, 2019; RÖGLINGER; PÖPPELBUSS; BECKER, 2012). Therefore, the asset management maturity model (AMMM) acts as a proxy to assess the delivery value of AM processes.

By analyzing AMMMs, Lima and Costa (2025) highlight gaps related to the absence of the assessment procedure, which enables the correct application of MMs, the absence of multiple evaluators, which enable a broad view of the AM processes, and the absence of the tools, which support the effective application. So, these challenges demand the development of a new AMMM, and mainly, the establishment of the assessment procedure that enhances the reference model application.

1.1. Justification and relevance

Asset-intensive industries are relevant to the economy and society. Illustrating an example for an economic perspective, the manufacturing sector plays a role in the Brazilian economy, which represents around 24.7% of gross domestic product (CONFEDERAÇÃO NACIONAL DA INDÚSTRIA, 2025). In contrast, the operation of railway transportation has been cited noise pollution as a drawback to the local community (SONG *et al.*, 2014; WRÓTNY; BOHATKIEWICZ, 2020; XIAOAN, 2006).

For these companies, assets play a decisive role in shaping organizational outcomes, as their performance directly influences the company's ability to achieve its strategic objectives. The failure of an asset reverberates across multiple dimensions of business performance, from operational efficiency and financial stability to safety and customer satisfaction. In this sense, managers need to develop effective AM practices that make the best use of the asset system.

However, in the daily routine, decision-makers in asset-intensive operations have demanded managerial tools to assist the decision-making process (SANDU; VARGANOVA; SAMII, 2023). Additionally, the AM literature review reveals that advancements in the decision-making process need to be achieved, structuring data and value for evaluations of alternatives (ALQURAIDI; AWAD, 2024; PETCHROMPO; PARLIKAD, 2019; SANDU; VARGANOVA; SAMII, 2023). In this context, ALQURAIDI; AWAD, (2024) emphasize that MMs promote informed decision-making.

In addition, the existing literature has not comprehensively investigated whether the effort, investment, and time dedicated to advancing AM maturity have resulted in improved business performance. The challenges related to data quality and availability, presented in the AM context, have constrained the assessment of the contribution of AM to business performance.

Consequently, empirical evidence must be generated using approaches that overcome the data challenges. The potential contributions are relevant to both professional practice and academic research. From an academic perspective, it would be progress in line with LIMA, ELIANA SANGREMAN; MCMAHON; COSTA, (2021), HAN et al., (2021) and MALETIČ et al., (2020) studies.

On the other hand, managers could use the findings to prioritize AM actions, describing that AM initiatives affect the performance, which is yet a locus of investigation (ALQURAIDI;

AWAD, 2024). In addition, it discovers empirical evidence of relationship between AM maturity and business performance, enhancing the usability and relevance of AMMMs.

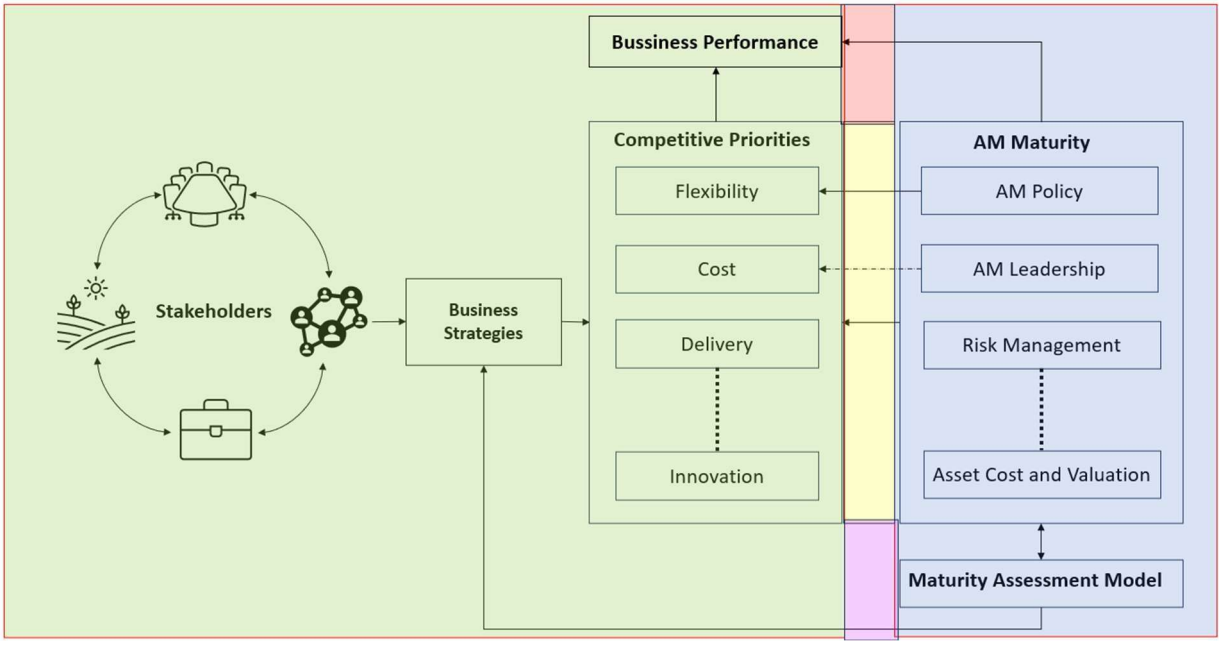
1.2. Problem description

Business literature demonstrates that internal and external stakeholders influence the development of business strategies, so that these strategies will be broken down into functional strategies (ROOVERS; VAN BUUREN, 2016; SOMOV, 2018). In order to demonstrate the adequacy of strategies to stakeholders' requirements, the organization develops competitive priorities, which are organizational objectives. Therefore, achieving these competitive priorities improves business performance.

Considering this strategic perspective, Herminio de Andrade Lima and Costa (2025) propose that the development of AMMMs enables the reconfiguration of strategies by taking into account the level of AM maturity and the level of fullness of AM processes (FIGURE 1). However, as mentioned, current AMMMs have some gap that needs to be addressed to allow the effective application of maturity self-assessment.

In this sense, this thesis proposes a novel AMMM that performs as a referential model, which is supported by a procedure model called AMAP – Asset Management Maturity Assessment procedure. AMAP assists asset-intensive organizations in measuring AM Maturity and its AM capabilities, considering the essential elements for maturity assessment.

FIGURE 1 - Problem description



Source: adapted from LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b)

In addition, some papers bring evidence that developing AM dimensions influences operational performance(HAN *et al.*, 2021). Specially, LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025a) exploit the relationship between the capabilities of AM dimensions and competitive priorities, e.g., validating that quality can be leveraged by the adoption of a solution related to AM Policy, Data and Information Management, and Asset Performance. Nevertheless, the causal relationship between AM maturity and business performance remains a gap in the AM literature, which can leverage the use and impact of AMMMs.

Therefore, the measurement of the delivery value of AM needs to be improved, promoting data and value for decision-making processes, as well as understanding the effects of AM on business performance.

1.3. Objectives

1.3.1. General objective

This thesis aims to develop an asset management maturity model implemented in a web decision support system that performs an assessment procedure, which enables asset-intensive organizations to apply it by themselves. With data from applications, this study advances to analyze whether AM maturity is related to business performance

1.3.2. Specific objectives

The following specific objectives are pursued:

- Proposing the referential model that contains the elements of an MM, describing them to guarantee replicability.
- Proposing the assessment procedure based on the self-assessment approach, which must be composed of elements needed to be an effective application, including an aggregation method for multiple assessments.
- Applying the validation process to guarantee the effectiveness and replicability of the AMMM proposed.
- Developing a theoretical model that explores the relationship between AM maturity and business performance.

1.4. The thesis structure

This thesis is structured as follows:

- Chapter 2: It provides a background of AM, highlighting AM core dimensions, challenges, and benefits. For the purpose of outlining a section of the maturity models field, the main concepts, gaps, and benefits are presented. After a review of MMs for AM is performed. Finally, this chapter touches on business performance literature and draws hypotheses of the AM maturity and business performance.
- Chapter 3: It describes the methodologies used to develop AMAP and test the theoretical model. In order to build AMAP, design science research approaches were applied. To establish the relationship between AM maturity and business performance, Partial least squares structural equation modeling was adopted.
- Chapter 4: It presents AMAP. Firstly, the main elements of MMs for AM are presented, which include well-defined AM classes. Secondly, the assessment procedure and DSS are presented.
- Chapter 5: The applications of AMAP in asset-intensive industries are summarized. Specifically, the validation of AMAP in assigning AM classes adjusted to AM practices of organizations is discussed. In addition, managerial and theoretical insights are explained, which demonstrate the usability of MMs for decision-making processes.

- Chapter 6: The results of the partial least squares structural equation modeling application are presented, demonstrating that AM practices contribute to business performance. Moreover, the findings indicate that some AM dimensions influence others.
- Chapter 7: The thesis closes with conclusions that emphasize its contributions and impacts, while also addressing limitations and suggesting directions for future research.

2 *THEORETICAL BACKGROUND*

In this chapter, the essential concepts around AM, Maturity Models, and Business performance are presented. As a result, gaps in MM for AM are highlighted, and a theoretical model is proposed for testing.

2.1. Asset Management

Initially, the background of AM is presented, explaining some theories and concepts that are essential to understanding the role of AM in asset-intensive industries. Some challenges and benefits are addressed to describe the landscape of AM. In addition, maturity models for AM are analyzed. Finally, concepts and evidence related to business performance are explained.

2.1.1. Background of Asset Management

Assets are organizational resources that assist the generation of goods and services, which can be classified as physical assets, informational assets, human assets, financial assets, and intangible assets (IAM, 2024). Specifically, this thesis focuses on engineering assets such as machines, vehicles, and equipment that organizations acquire, operate, maintain, and dispose of. Albeit there is this focus, it is necessary to develop and manage other assets when they impact the optimized management of physical assets. Therefore, AM managers must be able to create a set of organizational skills to operate assets.

These assets have emerged as a source of business competitiveness (SMITH; SHARIF, 2007), The effective operation of these assets is fundamental to the achievement of organizational objectives. For example, asset failure may generate financial losses, cause environmental damage, and pose risks to human safety (BOURASSA; GAUTHIER; ABDUL-NOUR, 2016) . Consequently, this event affects different organizational objectives, which are related to stakeholders' requirements.

So, considering the role of the asset on competitiveness, asset-intensive organizations must develop and manage their assets in order to assist in the organizational competitiveness. In this sense, the Resource-Based View theory (RBV) sustains that organizations that develop and implement valuable, rare, inimitable, and on-substitutable (VRIO) assets would result in competitive advantage (BARNEY, 1991). Then, to gain and maintain a competitive advantage, organizations should prioritize the efficient and strategic utilization of their assets.

In this perspective, whether the organization aims to achieve the best results from assets and obtain competitiveness, acquiring and developing distinctive assets are essential. Then, according to RBV, assets enable value-creating strategies that other asset-intensive organizations cannot readily copy (EISENHARDT; MARTIN, 2000) . Therefore, RBV turns assets into strategic resources, which must be developed to achieve efficiency and performance above the industrial average.

Nonetheless, some criticisms rely on the absence of asset definitions, the replicability of VRIO attributes, and the challenge in validating RBV hypotheses due to the firm heterogeneity (KRAAIJENBRINK; SPENDER; GROEN, 2010; LOCKETT; THOMPSON; MORGENSTERN, 2009). Illustrating this, it is often difficult to establish a direct and measurable relationship between business performance and any particular asset, since organizational outcomes usually result from a complex interaction of multiple resources, capabilities, and contextual factors (DE ALMEIDA, NUNO MARQUES *et al.*, 2021).

By investigating RBV in operating management, which is the focus of application and development of practices in physical assets, BROMILEY; RAU, (2016) emphasize that RBV is not adequate mainly due to the definition of rare and inimitable resources that constrain the replicability and proof of new practices. In other words, according to the VRIO attributes, assets that enhance competitiveness must be rare and inimitable; consequently, other organizations cannot reach the same level of development. Consequently, this perspective is not fully suitable for production management

Although RBV is inadequate to explain the competitiveness based on assets, mainly in operation management, there is evidence that the principles and understanding of management centered on assets are useful in the organizational practices (KRAAIJENBRINK; SPENDER; GROEN, 2010). Therefore, assumptions regarding the development, use, and operation of assets as strategic factors are not only useful but also necessary, encouraging a more comprehensive and long-term strategic perspective.

Considering these assumptions and the inadequacy of RBV, Dynamic Capabilities theory (DC) emerges to explain how and why certain firms have a competitive advantage in situations of rapid and unpredictable change (EISENHARDT; MARTIN, 2000). In this theoretical framework, organizations must develop and maintain organizational capabilities to manage their assets in order to adjust and adapt to market changes and requirements. Then, competitiveness is driven by organizational capabilities.

In the DC context, organizational capability can be defined as a higher-order routine, or a set of interrelated routines, which, combined with the necessary input flows, provides a range of decision-making alternatives to generate significant and specific results(WINTER, 2003). Contrasting RBV and DC theories, EISENHARDT; MARTIN, (2000) summarize some advances in dynamic capabilities about RBV theory:

- First, dynamic capabilities comprise specific processes that create value for the organization, developing strategies that manipulate assets to deliver value. These processes are more related to strategic and organizational perspectives than operational ones.
- Second, dynamic capabilities demonstrate similarity across organizations, albeit it does not imply equality. Thus, this commonality, called best practice, is contrary to the thinking suggested in RBV.
- Third, market dynamism impacts the pattern of dynamic capabilities chosen. For example, a mature market suggests one based on routine, whereas a new market implies experimental approaches.
- Finally, establishing learning mechanisms drives the development of dynamic capabilities and leads to path dependence. It is worth noting that multiple paths guide the same dynamic capability.

As can be noted, DC is based on a process approach. BITITCI, UMIT S. et al., (2011) demonstrate that managerial processes are interconnected routines that shape an organization's dynamic capabilities by managing and reconfiguring its resources, thereby influencing its long-term competitive advantage. Therefore, the focus is on the development of managerial processes that can control and reconfigure assets in order to achieve a competitive advantage.

On the other hand, the development and maintenance of DCs can be a source of competitive advantage, but not essentially a way to achieve competitive sustainability and advantage. In this context, DCs related to assets have been investigated, which have been called asset orchestration or AM capability in AM literature. This concept can be used and applied to capabilities or tangible and intangible assets (SCHRIBER; LÖWSTEDT, 2018). However, it will stand out in AM capabilities related to physical assets and its capabilities.

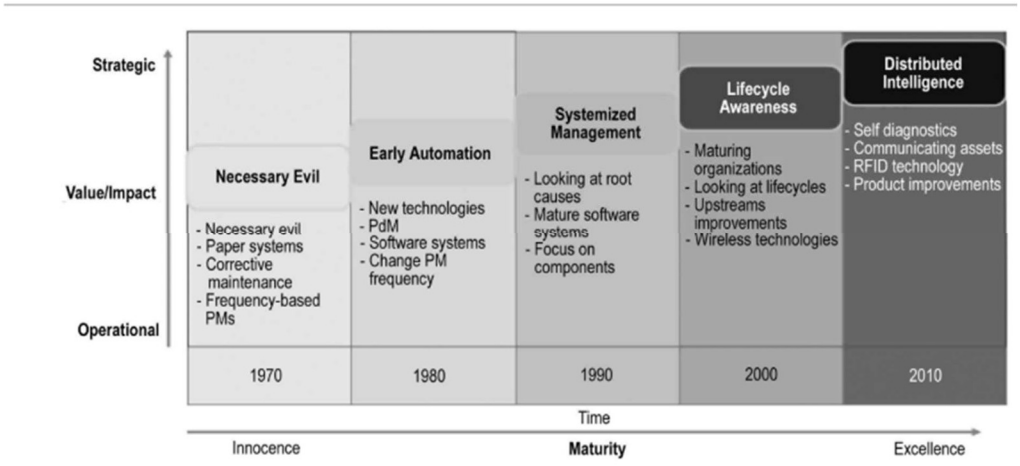
Asset orchestration emerges as organizational capabilities to configure assets to obtain more value from their assets, which is associated with the industrial environment (FAINSHMIDT; NAIR; MALLON, 2017). Investigating these capabilities, CAI; YANG,

(2014) found that asset frontier (capabilities based on tangible resources) influences the achievement of competitive priorities related to flexibility and delivery, as well as exerts constraints in operating frontiers (based on procedures and policies that constrain its operations). Then, considering the industrial dynamism, organizations need to improve their AM capabilities to achieve better results.

Historically, the focus of AM has been primarily on operational processes such as maintenance (LAUE *et al.*, 2014), that makes use of the maintenance management concept as AM (KONSTANTAKOS; CHOUNTALAS; MAGOUTAS, 2019). More specifically, the AM beginning is associated with terotechnology, which is defined as the integration of management, financial, engineering, and other practices applied to physical assets with the goal of optimizing economic life-cycle costs (THACKARA, 1975).

In this stage, reliability and maintainability are considered to manage the assets with a focus on reducing costs during the operation of the assets. As can be seen in Figure 2, which demonstrates the evolution of AM, in the beginning, maintenance activities were seen as a necessary evil that did not add value. In this stage, the goal of lifecycle management is the optimal utilization of the remaining lifetime, concerning a definite reliability and a constant distribution of costs for reinvestment and maintenance (SCHNEIDER *et al.*, 2006).

Figure 2 - Evolution of AM



Source: from KONSTANTAKOS; CHOUNTALAS; MAGOUTAS, (2019).

With advancements in understanding of the contribution of assets, including the impact on manufacturing and competitive priorities, the maintenance and management of assets

achieved a new degree: a strategic element to business. In this context, PINTELON; PARODI-HERZ, (2008) emphasize that a carefully designed maintenance program is essential to meet business, environmental, and safety objectives.

In this sense, an asset is not just a productive resource but also a valuable strategic resource to an organization that must be managed effectively. So, to guarantee that assets achieve the desired outcomes and identify the contribution of the maintenance process, performance management has been applied in maintenance, establishing indicators and measurement systems (MUCHIRI *et al.*, 2011; PARIDA *et al.*, 2015). Moreover, these indicators reflect the objectives of maintenance problems, which have moved from a focus on cost to a holistic focus (DE ALMEIDA, A. T.; FERREIRA; CAVALCANTE, 2015; MUCHIRI *et al.*, 2011; PARIDA; CHATTOPADHYAY, 2007).

Illustrating this holistic approach, there are indicators related to assets (OEE, availability, MTBF, production rate, vibration and thermography, and others) and processes related to management and controlling assets (maintenance cost, number of accidents, customer satisfaction, skills and competency development/training, employee satisfaction, MTTR, and others). It is worth noting that these indicators can be used to represent the hierarchical perspective of business, that is, strategic, tactical, and operational levels (PARIDA; CHATTOPADHYAY, 2007).

AM evolves progressively, moving from the asset-use phase under the supervision of maintenance management to more holistic approaches, culminating in a management framework that integrates the entire asset life cycle. Table 1 summarizes some AM definitions available in the AM literature, highlighting some elements.

Table 1 – AM definitions

DEFINITION	SOURCE
"systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated **performance, risks and expenditures** over their life cycles for the purpose of achieving its organizational strategic plan"	IAM, (2024)
"Coordinated activity of an organization (3.1.13) **to realize value** from assets"	ISO, (2024a)
"The life cycle management of physical assets to achieve the **stated outputs** of the enterprise"	Asset management council
"Formalized, corporate-wide ongoing process of continuous improvement for making decisions about assets that **balance costs, risks, and service** to support sustainable service delivery"	Asset-Management-for-Sustainable-Service-Delivery-A-BC-Framework-

"Asset management is an integrated business approach involving planning, finance, engineering and operations to effectively manage existing and new infrastructure to **maximize benefits, reduce risk and provide satisfactory levels of service** to community users in a socially, environmentally and economically sustainable manner"	National Roundtable for Sustainable Infrastructure defines
"The combination of management, financial, economic, engineering and other practices applied to physical assets with the objective of **providing the required level of service** in the most cost-effective manner"	International Infrastructure Management Manual
"Asset management is an integrated approach, involving all organization departments, to effectively manage existing and new assets to **deliver services to customers**"	Canadian Network of Asset Managers
"A systematic process to cost efficiently maintain, repair, and operate physical assets, it also provides a tool for systematic and theoretical approach to decision making based on the combination of **engineering principles, best practical methods, and economic theories**"	Federal Highway Administration (FHWA) of the United States
"Asset management can be defined as the coordinated activity of an organisation to **realise value** from assets, present and future"	NSW Government
"The combination of software, systems and services that maintain and control operational assets and equipment. The aim of EAM is to **optimize the quality and utilization** of assets throughout their lifecycle, increase **productive uptime and reduce operational costs**"	IBM

Source: This Research (2025)

By analyzing these AM definitions, it is possible to identify the main difference between AM and maintenance activities:

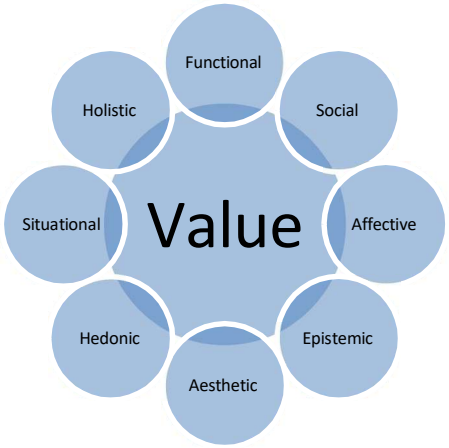
- Delivering value from assets, which is a broad concept.
- Integrating risk management.
- Developing an integrated approach across the business.

In AM context, value can be measured in tangible or intangible, financial or non-financial metrics (GFMAM, 2024). The value of AM practices has been studied in AM literature, including the development of methodologies to measure it (ALMEIDA, N. *et al.*, 2022; ISO, 2024a; RODA; MACCHI, 2018; SRINIVASAN; PARLIKAD, 2020; WOODHOUSE, 2019). The delivery of value is associated with attending to the stakeholders and the organization's requirements (GFMAM, 2024).

From this perspective, value becomes evident when the organization demonstrates the fulfillment of both stakeholder expectations and its own objectives. In order to support AM decision-makers in understanding the main dimensions of value for stakeholders, ALMEIDA,

N. et al., (2022) categorize value in AM in eight dimensions (Figure 3). Consequently, AM processes aim to achieve these requirements that cover a range of value concepts.

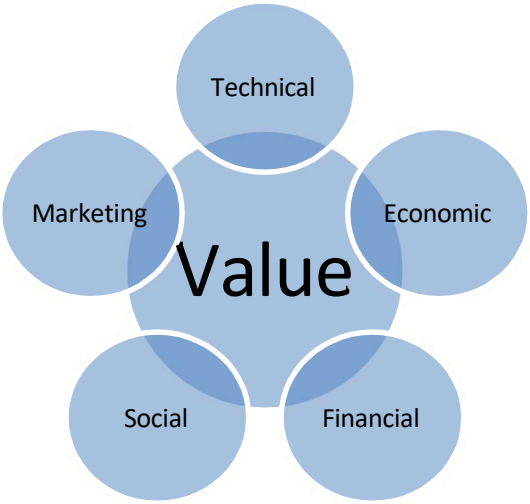
Figure 3 – Value dimensions for external stakeholders



Source: adapted from ALMEIDA, N. et al., (2022).

As introduced, AM brings many benefits to organizations (ISO, 2024a). Then, AM processes must seek to achieve business value in relevant value dimensions for the organization, which, as previously stated, demands a multidimensional approach (Figure 4). For example, the implementation of new digital technologies to support AM creates new ways to deliver value to businesses using assets (LOVE; MATTHEWS, 2019).

Figure 4 – Value dimensions for organizations



Source: adapted from ALMEIDA, N. et al., (2022)

By proceeding with considerations around AM definitions, AM activities are driven by risk management approaches. Risk is inherent in daily routines and closely linked to the concept of uncertainty (NORDGARD, 2010; PIYATRAPOOMI; KUMAR; SETUNGE, 2004). Consequently, the organizational environment is affected by random events. These events may provoke failure in asset systems, which affect the achievement of operational objectives and, consequently, the organizational objectives.

In the context of complex systems, characterized by multiple interacting and interdependent components, such uncertainty amplifies the probability of extreme, rare, and disruptive events (KOMLJENOVIC *et al.*, 2016; SYED; LAWRYSHYN, 2020). Due to this scope, stakeholders exert pressure on activities to reduce and mitigate the risk in the operation, which includes compliance with regulatory laws (E. CANTOR et al., 2014;LIMA, E. S.; CABRAL SEIXAS COSTA, 2019;SCHÄFER; HIRSCH; NITZL, 2022)

Traditionally, a risk approach comprises risk assessment and risk management (SYED; LAWRYSHYN, 2020). Risk assessment involves activities to identify and evaluate risk, which include determining the risk types associated with the operation, for example, environmental risk, regulatory risk, safety risk, and reputational risk (NORDGARD; SAND; WANGENSTEEN, 2010). In this context, there are both qualitative and quantitative methods to support decision-makers in risk assessment activities (ISO, 2018; NORDGARD; SAND; WANGENSTEEN, 2010).

Risk management comprises coordinated activities to direct and control an organization with regard to risks, which effectiveness depends on its integration into governance and all organizational activities, including decision-making (ISO, 2018). So, organizations develop strategies to mitigate risks, for instance, by adopting resilience approaches to effectively manage uncertainties in supply chain operations (CAN SAGLAM; YILDIZ ÇANKAYA; SEZEN, 2020).

AM emerges as a discipline that aggregates activities and practices in which the organization manages assets and asset systems to achieve value from assets while balancing cost, risk, and performance (ISO, 2014; IAM, 2008). Thus, AM has been acknowledged as an umbrella and interdisciplinary perspective, which involves developing holistic approaches that consider the entire life cycle of the asset (EL-AKRUTI; DWIGHT; ZHANG, 2013; SCHUMAN; BRENT, 2005). In the next subsection, AM dimensions are presented.

Before explaining the multidisciplinary approach of AM, it is fundamental to highlight the benefits of implementing and developing AM initiatives. Initially, AM practices promote financial and non-financial contributions to business, albeit the benefits face challenges to measurement. In contrast, DE ALMEIDA, NUNO MARQUES et al., (2021) stand out that organizations that implement AM programs demonstrate enhanced capabilities in risk management, information management, and decision-making processes.

Moreover, ISO, (2024a) structures the main benefits of applying AM systems:

- Improved financial performance.
- Informed asset investment decisions.
- Managed risk.
- Improved services and outputs.
- Demonstrated social responsibility.
- Demonstrated compliance.
- Enhanced reputation.
- Improved organizational sustainability.
- Improved efficiency and effectiveness.

Similarly, IAM, (2024) highlights the more present AM benefits in organizational practices:

- Greater customer satisfaction through delivery of products/services to required standards.
- Improved health, safety, and environmental performance.
- Optimized return on investment and/or growth.
- Long-term planning, confidence, and performance sustainability.
- Ability to demonstrate best value-for-money under constrained funding conditions.
- Evidence of legal, regulatory, and statutory compliance through systematic processes.
- Enhanced risk management and corporate governance with a clear audit trail of decisions and risks.
- Strengthened corporate reputation, including higher shareholder value, better marketability, greater staff satisfaction, and more efficient procurement.

- Ability to demonstrate active consideration of sustainable development throughout the asset life cycle.

It is worth noting that ISO and IAM have not attempted to establish a definitive view of AM benefits, but rather to highlight the most evident benefits across the AM landscape. In light of this, researchers have sought studies to bring empirical evidence for establishing the causal link between AM practices and performance.

In the European context, ALSYOUF et al., (2021) exploit asset-intensive organizations certified in ISO 55001 with regard to the four perspectives of balanced-score card, financial, customer, business process, and learning and growth perspectives. The findings suggest that AM implementation can influence multiple dimensions of business, except in market share.

In addition, as mentioned in the introduction, empirical investigations have revealed that capabilities related to AM, such as AM strategy, personnel, IT infrastructure (asset information), life cycle delivery, risk management, performance evaluation, and improvement, influence operational and manufacturing performance (HAN *et al.*, 2021; LIMA, ELIANA SANGREMAN; MCMAHON; COSTA, 2021; MALETIČ *et al.*, 2018, 2020).

2.1.2. AM dimensions

AM demands on both strategic and operational practices; consequently, AM dimensions reflect the level of hierarchical decisions. In this scenario, AM processes address activities of organizing, managing, planning, and controlling human resources, technologies, and information, while maintaining control of environmental factors (LAUE *et al.*, 2014). These environmental factors can be identified as stakeholder management, risk and sustainability management, inter-organizational collaboration, and governmental regulatory framework. (LAUE *et al.*, 2014).

Similarly, POLENGHI et al., (2022) identify key processes in AM, namely life cycle orientation, system orientation, risk orientation, value orientation, company culture, organizational structure, multidisciplinary orientation, information management and integration data to information transformation, and data collection. The AM dimensions related to information are key dimensions in asset-intensive industries. Therefore, data management and governance emerge as essential activities to implement AM initiatives.

By analyzing the AM literature from 1991 to 2019, JUNG; KIM, (2021) investigate the words that appeared most in large proportions during these years. It is possible to find words

related to different AM dimensions, such as evaluation cost, performance, reliability, analysis, planning, and control. In addition, system and maintenance have appeared as relevant words throughout the decades. As mentioned, maintenance practices are common activities in AM, as well as system has demonstrated essential to support the different AM processes.

By considering the benefits, requirements, and demands of integrating AM practice within enterprises, it has emerged institutes, such as International Asset Management, the Global Forum on Maintenance and Asset Management (GFMAM), *Associação Brasileira de Manutenção e Gestão de Ativos,* Malaysian Asset and Project Management Association, and the Asset Management Council in order to investigate and develop international standards to improve AM practices. These institutes have provided a systematization of AM dimensions.

ISO, (2024a), for example, developed the ISO 5500x series, which provides some principles to develop an effective AM system. These principles demand some AM dimensions, which, once achieved, deliver value from the asset. The principles and their dimensions are:

- Context of organization: understanding the organizations and its context, understanding the needs and expectations of stakeholders, determining the scope of the asset management system, asset management system.
- Leadership: leadership and commitment, policy, organizational roles, responsibilities, and authorities.
- Planning: actions to address risks and opportunities for the asset management system, asset management objectives, and planning to achieve them,
- Support: resource, competencies, awareness, communication, information requirements, and documented information.
- Operation: operational planning and control, management of change, outsourcing.
- Performance evaluation: monitoring, measurement, analysis, and evaluation, internal audit, management review
- Improvement: nonconformity and corrective action, preventive action, continual improvement

Another reference in the AM context is the GFMAM. By investigating AM practices across asset-intensive industries, GFMAM establishes a set of common practices that are present in enterprises where assets are central to the operation. In this manner, GFMAM, (2024) has published forty AM capabilities that are common in AM routine, categorized in five AM

groups: strategic & planning, asset management decision making, asset information, lifecycle delivery organization & people, collective decision making, risk & review. Table 2 summarizes AM dimensions, organized by AM groups. Appendix A describes the definitions to each AM dimension.

Table 2 – AM Dimensions proposed by GFMAM

Group	GFAM Dimension	Group	GFAM Dimension
Strategy & Planning	AM Policy	**Asset Management Decision-Making**	Operation and maintenance decision-making
	AM strategy and objectives		Resourcing strategy
	Demand analysis		Lifecycle value realisation
	Strategic planning		Capital investiment decision-making
	AM Planning		Shutdown and outage strategy
Asset information	Data e information Management	**Lifecycle Delivery**	Asset creation & Acquisition
	Asset information standards		asset Decommissioning e Disposal
	Asset information strategy		System engineering
	Asset information systems		Technical standards e legislation
			Configuration management
Organisation & People	Stakeholder Engagement	**Collective decision making**	Reliability Engineering
	Sustainable development		Resource Management
	Management of Change		Fault and Incident Response
Risk & Review	Risk assessment e management		Asset operation
	Management review, audit and assurance		Shutdown and Outage Management
	Contigency planning and resilience analysis		Maintenance delivery
	Asset management system monitoring		Procurement e supply chain management
	Asset cost e valuation		AM Leadership
	Asset performance e health monitoring		Competence management
			Organizational culture
			Organizational structure

Source: This Research (2025)

As can be seen, AM dimensions provided by references, and mainly the ones organized by GFMAM, (2024), demonstrate the holistic perspective of AM. In other words, asset-intensive companies need to make decisions that consider a range of organizational issues. For

example, many AM dimensions are related to silos of managerial knowledge such as demand analysis, organizational culture, data and information management, leadership, and audit, which are common in the daily routine of an enterprise.

On the other hand, as asset-centered decisions are relevant to decision-making processes in asset-intensive situations, AM dimensions have been established to address them . In this sense, it emerges AM dimensions to assist in the design of intervention policy, budget allocation, asset prioritization, asset disposal, and asset selection (PETCHROMPO; PARLIKAD, 2019). Similarly, AM dimensions related to maintenance and asset performance have been considered in this scope, which are relevant to an effective AM (AMADI-ECHENDU, 2004; LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b; MIRHOSSEINI; KEYNIA, 2021).

By considering this landscape, the strategic scope is also present, which is responsible for the development of strategies and plans for AM at a corporate level, while providing operational strategies to deliver value from assets and AM processes to stakeholders. In view of the role of stakeholders in AM initiatives, the decision-maker must involve multiple purposes of value aligned to different stakeholders (AMEKUDZI *et al.*, 2002; OBICCI *et al.*, 2025). In this perspective, new capabilities have been incorporated in the AM framework, such as engagement of stakeholders, sustainability development, and technical standards and legislation.

Although this big picture is composed of all these AM dimensions, most enterprises and AM frameworks do not cover all dimensions in their initiatives. Consequently, enterprises must consider their organizational context and objectives to prioritize the AM capabilities that are essential to achieving organizational objectives from AM (AL MARZOOQI; HUSSAIN; AHMAD, 2019; IAM, 2024). In order to support the prioritization of AM dimensions, some methods have been proposed, e.g. FROLOV et al., (2010) present an approach that can be applied, while other papers describe core dimensions in the AM context (LAUE *et al.*, 2014; LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b; MALETIČ *et al.*, 2020).

Each dimension deals with different decisions, which require different methods to support recommendations. Uncertainties in the system must be considered in the AM context to support planning and control activities, which have incorporated stochastic methods to model uncertainties (KAHAGALAGE *et al.*, 2024). On the other hand, multi-objective optimization and multi-criteria decision analysis approaches have been applied using operational and

reliability factors such as downtime, cost, and makespan (PARIDA *et al.*, 2015; PETCHROMPO; PARLIKAD, 2019). However, strategic AM, decision-making, and sustainable performance have been few explored in AM literature (SANDU; VARGANOVA; SAMII, 2023).

Albeit many decisions are at operational levels, their effects may have a long-term influence (KOMONEN; KORTELAINEN; RÄIKKÖNEN, 2012). For example, decisions involving assets in the sewer system, which have a long lifespan, have effects for many years (TSCHEIKNER-GRATL *et al.*, 2019). Consequently, AM decisions are relevant to asset-intensive organizations, which can influence the achievement of organizational objectives.

2.1.3. Emergent technologies in AM

Advancements in digital technologies have changed the production systems (ALCÁCER; CRUZ-MACHADO, 2019; LOVE; MATTHEWS, 2019; USMANI; HAPPONEN; WATADA, 2023). Some examples of these technologies are:

- Internet-of-things (IoT): describes a system of physical devices that can transmit their data via the internet, which supports the decision-making process in the AM context (BROUS; JANSSEN; HERDER, 2019).
- Cloud computing: refers to an Internet-based system for computation and resource management, in which shared resources and information are delivered and accessed on demand (LU, 2025).
- Big data: refers to extremely large, complex, and diverse data, for which traditional tools are not enough to manage and extract patterns for decision-making (CAMPOS *et al.*, 2017)
- Analytics: encompasses the techniques, technologies, systems, practices, methodologies, and applications designed to analyze critical business data, enabling organizations to support timely and informed decision-making (CHEN; CHIANG; STOREY, 2012)

Recently, the intensive use of these technologies enabled the emergence of Industry 4.0, which is acknowledged for using high technologies that allow for gathering and analyzing data in real time to provide high automation and production (FRANK; DALENOGARE; AYALA, 2019; LU, 2025). In addition, Industry 4.0 technologies have been applied in the AM context

to achieve sustainable objectives (BIARD; NOUR, 2021; SANDU; SAMII, 2021), being topic trends: machine learning, artificial intelligence, predictive maintenance, data analysis, IoT, cloud computing, and big data (WEERASEKARA *et al.*, 2022).

The deep use of these technologies has demanded the development of modelling techniques. Investigating the maximization of the lifecycle of the asset in diverse AM areas related to reliability, availability, maintainability, safety, and prognostics and health management, PAYETTE; ABDUL-NOUR, (2023) argues that the AM research addresses solutions using data-driven, physics-based, and hybrid models, including a broad range of applications involving machine learning in this universe.

Among the Industry 4.0 technologies applied in the AM context, digital twins are a relevant tool in asset-intensive organizations. Digital twins are tools composed of models, communication provided by IoT and sensors, simulation, Artificial Intelligence, and big data, which allow organizations to develop digital systems similar to physical ones (KRISHNAMENON *et al.*, 2021; LI *et al.*, 2024). Some examples of digital applications are common in maintenance and operation activities (ALHADI; DR TOM; YACINE, 2025). However, some challenges have appeared regarding data governance, cost, operational issues, complexity, and lack of protocols (ALHADI; DR TOM; YACINE, 2025).

The IoT technologies enable monitoring of asset systems, enabling the application of different models. In this sense, TEOH; GILL; PARLIKAD, (2023) propose a predictive maintenance plan using a genetic algorithm and machine learning models, which use data from metrics of the condition asset. LEE, CARMAN KA MAN; NA; KIT, (2015) developed an AM system for healthcare companies, which is composed of IoT, Artificial Intelligence, and Fuzzy. WANG, LUNSHENG; GAO; LIANG, (2021) propose a framework to asset valuation using IoT, data envelopment, and particle swarm optimization. In addition, IoT adoption requires new organizational competencies, e.g., data governance and change management (BROUS; JANSSEN; HERDER, 2019).

Machine learning models have been applied in the AM context, as mentioned previously. RAJORA et al., (2024) investigate the development of machine learning modelling in electric power systems, finding diverse approaches and applications, such as fault detection, predictive maintenance, forecasting, and data-driven fault diagnosis. By considering the construction sector, RAMPINI; RE CECCONI, (2022) demonstrate that machine learning models have been applied, for example, to monitor the asset condition. In railway operation,

CONSILVIO et al., (2020) propose a framework to support the strategic, tactical, and operational activities of AM.

Another technology that has been used in AM operations is the Geographic Information System (GIS). GIS assists in the integration of geographical and non-spatial data, enabling the visualization of datasets within a spatial context (GASBARRI *et al.*, 2024). By integrating GIS in an AM solution, GONZÁLEZ-CANCELAS et al., (2025) propose a system to improve asset monitoring and maintenance management. In infrastructure, GIS has been incorporated into the AM system to provide bridge maintenance (SALIM; STRAUSS; EMCH, 2002)

By investigating the barriers to the adoption of Industry 4.0 technologies, RAJ et al., (2020) finding that enterprises have a lack of digital strategy, combined with limited resources, high investment, and resistance to change. Their results suggest that improvements in internal capabilities can overcome the barriers. In another perspective, VERMA; VENKATESAN, (2023) propose that enterprises must manage their workforce to leverage the Industry 4.0 implementation. Finally, other challenges appear in the Industry 4.0 literature, namely, interoperability, data quality, cybersecurity, and specialized skills (BIARD; NOUR, 2021; LU, 2025; USMANI; HAPPONEN; WATADA, 2023).

Therefore, Industry 4.0 technologies are present and growing in the AM context. Considering these challenges and the locus of investigation of this thesis, it stands out that the improvement of organizational capabilities related to AM exerts an influence on the use and adoption of these technologies, given that most challenges rely on managerial capabilities.

2.1.4. AM challenges

By considering the landscape previously presented, some challenges have been addressed in AM literature. Firstly, the holistic approach of AM demands integration of data across the organization (IAM, 2024), which has demanded the use of AM systems (OUERTANI; PARLIKAD; MCFARLANE, 2008). In this sense, data in the AM context comes from a range of sources, such as operations, players, the market, and legislation. Then, challenges concerning data management, quality, availability, and interoperability have been identified in the AM context, which must be overcome (DAULAT *et al.*, 2024; IAM, 2024; PARLIKAD, A.K.; JAFARI, 2016; SHAH; MCMANN; BORTHWICK, 2017; TSCHEIKNER-GRATL *et al.*, 2019).

However, data governance has challenges associated with data ownership, governance mechanisms, and mainly, the measurement of the effectiveness of data governance on business performance (Abraham et al., 2019). Given the importance of Asset Information and the challenges handled by asset managers, ISO, (2024c) has published ISO 55013 to provide support to managing data in AM, which covers decision-making, governance, interoperability of the data asset, and delivery value, to achieve AM objectives. However, the increase in documentation and bureaucracy required by ISO can hinder its application (MALETIČ *et al.*, 2023)

Along with these challenges, technological advancements have brought some challenges for the AM context. In this respect, USMANI; HAPPONEN; WATADA, (2023) highlight that interoperability is crucial to the AM system in the Industry 4.0 era. Specifically, asset-intensive organizations need to develop expertise to integrate these new technologies with the legacy systems. To be more precise, the old systems used by organizations, which contain data, information, procedures, and roles, need to be added to the new system.

Organizational structure exerts influence on the implementation and control of AM initiatives (IAM, 2008). ABDELMOTI et al., (2025) describe that the absence of skills in communication and coordination activities can lead to organizational problems, mainly in large companies. On the other hand, another obstacle in the AM context is maintaining and developing experienced people (BEITELMAL *et al.*, 2017; IAM, 2024; SHAH; MCMANN; BORTHWICK, 2017). In addition, top management support is essential to implement AM initiatives (BEITELMAL *et al.*, 2017; IAM, 2024). As mentioned, AM demands an interdisciplinary approach, which causes cultural change. Then, culture change management emerges as a challenge (PARLIKAD, A.K.; JAFARI, 2016).

In this context, as mentioned, asset-intensive organizations must seek to balance cost, performance, and risk (IAM, 2024; ISO, 2014), which set a challenge in the AM routine (CHATTOPADHYAY, 2016). Some reasons for this challenge are the complexity of the AM system, which is composed of interplay processes and dependence between assets (DAULAT *et al.*, 2024; IAM, 2024), which need to be managed. Therefore, performance, monitoring and cost, and valuation have been applied to support AM activities. However, the reliability models have shown complex (RAFATI; TAHAVORI; SHAKER, 2025).

By analyzing the AM literature, JUNG; KIM, (2021) reveal ‘decision making’, ‘analysis’, and ‘model’ are more popular themes in AM. However, the AM decision-making

process has presented some challenges in different aspects. SANDU; VARGANOVA; SAMII, (2023) and PARLIKAD, A.K.; JAFARI, (2016) emphasize that managers need decision-making support tools to assist AM processes. For example, decision-makers in asset-intensive contexts require tools to analyze data quickly, which have demanded technologies with Artificial Intelligence (GOMES CORREIA; FERREIRA, 2023). Coupled with these challenges, considering value, data, and holistic objectives in AM decisions needs to be structured in AM problems (PETCHROMPO; PARLIKAD, 2019).

The decision-making process is not just related to the operational level. AM has demanded strategic approaches (IAM, 2024; SANDU; VARGANOVA; SAMII, 2023), and some challenges have emerged. For example, there is an absence of empirical evidence between asset management strategies, business performance, and competitive advantages (GAVRIKOVA; VOLKOVA; BURDA, 2020). In another perspective, in public agencies that manage infrastructure assets, SCHRAVEN; HARTMANN; DEWULF, (2011) identify the main challenge faced by AM managers is to make the alignment between AM decisions and the objectives formulated for AM.

Considering this perspective, BEITELMAL et al., (2017) found that strategic aspects, e.g., a lack of strategic plans for the organization, have been a challenge in developing AM effectiveness. Consequently, any decision made in this phase – strategic AM - influences the lifecycle of AM, including AM performance (CHATTOPADHYAY, 2016). In addition, another obstacle to asset-intensive organizations is a lack of understanding of the budget constraints and shortage of financial resources, which affects the implementation and establishment of AM (BEITELMAL *et al.*, 2017; CHATTOPADHYAY, 2016).

Finally, the operation of assets presents risks of system failures, as well as the decision-making demands simulation of scenarios to model the uncertainty in AM decisions. Informed decision-making decreases the probability of catastrophic system failures, major budget surprises, and claims from non-performant systems, thus reducing the long-term costs of operations (TSCHEIKNER-GRATL *et al.*, 2019). Therefore, managers need to manage the risk associated with asset operations.

It is worth noting that this challenge is not just connected with the absence of technologies, but also with skills and capabilities to enable adoption, use, and maintenance in decision-making processes. Therefore, organizations need to prioritize the improvement of AM

capabilities, such as the dimensions provided in Table 2. In order to support the assessment of capabilities, maturity models (MMs) can be used.

2.2. Maturity models

2.2.1. Maturity model

Organizational maturity describes how effectively and consistently processes are used to attain organizational objectives projected for them (PAULK *et al.*, 1993). In this sense, an organization is considered mature when its managerial capabilities are widely enabled to develop and maintain the achievement of specific goals (ISO, 2008; PAULK *et al.*, 1993). In contrast, immature organizations provide improvised processes with the absence of compliance with the standards and procedures described in the project phase (PAULK *et al.*, 1993). Therefore, organizational maturity measures the ability of the organization's processes to be widely effective in operations.

By analogy, AM maturity can be defined as to extent AM processes are effective in assisting in the achievement of AM objectives, that is, the organization has well-developed and operating AM processes akin to best practice with solid experience in AM (Commerce Commission, 2011). Therefore, AM maturity is reflected in its AM capabilities which are essential to promote success (ISO, 2024a), and success is related to delivering value to stakeholders.

In this context, the demand for how to evaluate organizational maturity emerges. For this, MMs act as managerial tools that assess the maturity level of processes, enabling organizations to rank the process considering the level of maturity of current practices (WENDLER, 2012). In other words, MMs perform as a framework to assess the development stages of business processes through structured maturity levels (MAHMOOD *et al.*, 2015), which guides how to create ways for improving the performance of process capability in the direction of the best practice (VAN LOOY *et al.*, 2013).

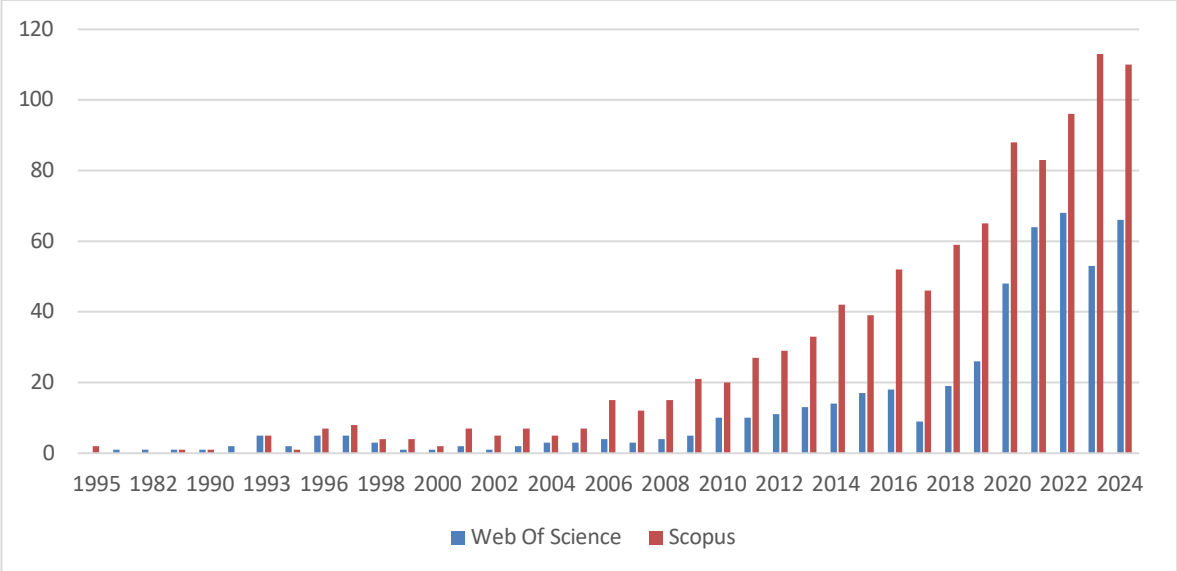
MMs have elements to establish the correct application and provide an understanding of the model (ISO, 2008; PAULK *et al.*, 1993; PROENÇA; BORBINHA, 2016) :

- Process and activities: MMs assess the capabilities of processes, sub-processes, or activities.

- Maturity level: defines the evidence for maturity. This level can be used to determine the maturity class.
- Maturity class: is defined as a label designed to represent how mature an organization is following evolutionary stages.
- Instrument to measure: MMs must use a method to measure the maturity. It is possible to use questionnaires, surveys, and checklists.

MMs were introduced in the software industry during the 1990s with the Capability Maturity Model Integration (CMMI), their extensive application in various other sectors has proven their usability and efficiency beyond the confines of software development due to the successful outcomes associated with MMs (KUCIŃSKA-LANDWÓJTOWICZ *et al.*, 2024; LEE, DONGHUN; GU; JUNG, 2019; WENDLER, 2012). In this perspective, it is possible to find MMs in Industry 4.0 (ASDECKER; FELCH, 2018; SANTOS; MARTINHO, 2019) sustainability (DÍAZ; ALENCAR; MOTA, 2025), lean supply chain (SOARES *et al.*, 2021), healthy care (KOLUKISA TARHAN et al., 2020), and others. To illustrate the popularity and use of MMs, Figure 5 presents the number of publications on this topic, which demonstrates the growth.

Figure 5 – Trend of maturity models in literature



Source: This Research (2025). Note: The Web of Science and Scopus publications. Key "maturity model", excluding proceedings (1995-2024).

With this growth, three purposes for using MMs have emerged:

- In the descriptive purpose, the organization identifies its weaknesses and strengths in its capabilities, undertaking a “here and now” analysis to obtain a panoramic view of its current maturity (DE BRUIN; HEALTH; ROSEMANN, 2005).
- If the organization intends to compare itself with the best practices of the standard of industry, in this case, an MM must serve as a benchmark (DE BRUIN; HEALTH; ROSEMANN, 2005). Thus, the organization can see its weaknesses and strengths concerning the industry's best standard, albeit it is difficult to develop the behavior of the best companies to contrast. Likewise, a benchmarking approach can be used for internal benchmarking (RÖGLINGER; PÖPPELBUSS; BECKER, 2012).
- In a prescriptive purpose, the maturity assessment provides a roadmap or guidelines to improve the maturity (RÖGLINGER; PÖPPELBUSS; BECKER, 2012). Although it may be effective to enhance actions related to each level of maturity, the literature has shown that this purpose is the minority in the applications (SANTOS-NETO; COSTA, 2019).

To support the application, MMs can be assisted by the assessment model, which establishes a detailed process of steps to determine the organization’s maturity level (BITITCI, UMIT S. *et al.*, 2015; PROENÇA; BORBINHA, 2016; PULPARAMBIL; BAGHDADI, 2019). In other words, these assessment procedures should include assessment techniques, such as interview views, questionnaires, document-based assessments, and consulting toolkits (PULPARAMBIL; BAGHDADI, 2019). On aspects of this procedure, it is the way the application will be guided, which can be made in three configurations (DE BRUIN; HEALTH; ROSEMANN, 2005; METTLER; ROHNER; WINTER, 2010):

- Third party: external professionals support the maturity assessment.
- Self-assessment: a systematic and comprehensive process to collect evidence of maturity and process capabilities by organizations themselves.
- Certified practitioners: external practitioners completely make maturity assessment.

MMs are reference models that provide elements of each process in assessment, establishing them in a sequence between the ad hoc and the desired stage of the process, that is,

in an evolutionary path (BECKER; KNACKSTEDT; PÖPPELBUSS, 2009; BITITCI, UMIT S. *et al.*, 2015). In addition, there is a misunderstanding about the reference model and process. Probably, this boosts the statistic that there is a lack of assessment procedures in most MMs (LACERDA; VON WANGENHEIM, 2018; SANTOS-NETO; COSTA, 2019). Consequently, due to the absence of enough information to guide the application, the applicability and the results may be constrained.

But what are the benefits of using MMs in companies? Firstly, it is worth noting that a MM enables enterprises to measure the expected performance taking into account the capabilities achieved in assessment, consequently allowing development roadmaps for improvements. Similarly, MMs assist in the identification of issues and guide the improvement of efficiency, effectiveness, performance, and productivity(KOLUKISA TARHAN *et al.*, 2020). Additionally, BITITCI, UMIT S. et al., (2015) highlight that MM guides the learning process and continuous improvement, which increases the creation of new solutions and maintains the process of improvement continuously.

Coupled with these benefits, MMs guided by a self-assessment application go beyond the benefits pointed out above (MACKERRON; MASSON; MCGLYNN, 2003). Organizations that apply self-assessment approaches also encourage employee involvement and ownership, increase the ability to meet and exceed customers' expectations, and develop a common approach to improvement across the company (RITCHIE; DALE, 2000).

Despite these benefits, there is a challenge in the BPM field about whether maturity impact on business performance (SANTOS-NETO; COSTA, 2019). This also applies in the AM context, which the literature has not thoroughly examined in depth, if the effort, investment, and time spent on developing AM maturity have been translated into better business performance. Hence, to achieve the maximum benefits, it is essential to ensure the appropriate and effective use of MMs through the assessment procedure and the best understanding of the relationship between AM and business performance

2.2.2. Asset management maturity model

Making a comparative analysis among the existing MMs provides an opportunity to develop a novel MM (BECKER; KNACKSTEDT; PÖPPELBUSS, 2009). For this, some criteria have been established to compare MMs. DE BRUIN; HEALTH; ROSEMANN, (2005) establish some categories, namely, the focus on the model, the level of interaction with

stakeholders, the method designed for applications, the driver of application, the respondents, and the application. On the other hand, by addressing these criteria, METTLER; ROHNER; WINTER, (2010) describe the topic, the origin, audience, access type, concept of maturity, composition, reliability, mutability, method of application, support of application, and practicality of evidence. Finally, PÖPPELBUSS MAXIMILIAN RÖGLINGER, (2011) point as criteria: basic information, definition of central constructs related to maturity and maturation, definition of central constructs related to the application domain, target group-oriented documentation, procedure model advice on the assessment of criteria, advice on the adaptation and configuration criteria, and expert knowledge from previous applications.

Then, the following attributes were adopted: origin, focus, type of access, method of application, support of application, typical purposes, procedure model, and class numbers. By analyzing the literature and the enterprise reports, we have found 19 AMMMs (Table 3) developed by academia and practitioners, thus demonstrating their spread in the academic and business context. In order to facilitate the organization, to each AMMM a code is adopted.

Table 3 – Asset Management Maturity Models

CODE	NAME	REFERENCE
1	Updated IM3	GERSONIUS et al., (2020)
2	IM3 Matrix	VOLKER et al., (2011)
3	SAMF	ABDELHAMID; BESHARA; GHONEIM, (2015)
4	LSM MM	MAIER; SCHMIEDBAUER; BIEDERMANN, (2021)
5		KHALIQ; MAHMOOD; DAS, (2015)
6		SISWANTORO et al., (2022)
7	AMCaMM	ASSET INSTITUTE, (2021)
8	AMAF	STATE OF VICTORIA, (2017)
9	AM Maturity Assessment Tool	INSTITUTE OF PUBLIC WORKS ENGINEERING AUSTRALASIA, (2021)
10	AMMAT	COMMERCE COMMISSION OF NEW ZEALAND, (2011)
11	AM Readiness Scale	FEDERATION OF CANADIAN MUNICIPALITIES, (2018)
12	Transit Agency AM Maturity Self-Assessment	FEDERAL TRANSIT ADMINISTRATION, (2017)
13	PAMCAM	GOVERNMENT PROPERTY PROFESSION, (2014)
14	Ofwat	OFWAT, (2017)
15	AMP	CAPEGEMINI, (2017)
15		WIJNIA, YPE; DE CROON, (2015)

17	AM Framework	MFOA, (2018)
18	ISO 55000 Overview and Simple Assessment	LCE, ([s. d.])
19	SAM+	IAM, (2014)

Source: This Research (2025).

VOLKER et al., (2011) develop the IM³ matrix that proposes to measure infrastructure AM maturity, using seven AM processes, namely, AM decisions, Information, management, Internal coordination, External coordination, outsource activities, processes and roles, and culture and leadership. In order to improve this model, GERSONIUS et al., (2020) added hierarchical levels. That is, the IM3 matrix was updated to address the strategic, tactical, and operational levels of AM processes. In addition, to be assigned to an AM maturity class, the consensus among employees (3 to 5) involved in the maturity assessment must be achieved.

ABDELHAMID; BESHARA; GHONEIM, (2015) present SAMF (Strategic Asset Management Framework), an AMMM developed to assess the management of buildings, considering the strategic approach of AM. It is worth noting that the SAMF uses AM activities common in AM fields, albeit it does not use AM literature to bring evidence around this. Moreover, AM dimensions are grouped in People and organization, Strategic planning, processes and practices, and data and information.

Based on the Lean Smart Maintenance, MAIER; SCHMIEDBAUER; BIEDERMANN, (2021) propose an AMMM composed of nine AM dimensions, including asset strategy. In addition, the authors adopted an assessment procedure composed of five groups of processes (define, measure, act, improve, and control), which can be applied by an organization to realize the AM maturity assessment. In addition, the AMMM proposed by them used design science research, which is a methodology useful for developing organizational solutions (HEVNER *et al.*, 2004), such as maturity models (PÖPPELBUSS MAXIMILIAN RÖGLINGER, 2011).

KHALIQ; MAHMOOD; DAS, (2015) introduce an AMMM focused on the electrical power context. In order to build it, electrical power literature and reports were consulted, which is a way to develop new MMs (DE BRUIN; HEALTH; ROSEMANN, 2005). However, they do not mention the reasons for the establishment of the AM maturity classes proposed, which has set a common issue in the MM field (RÖGLINGER; PÖPPELBUSS; BECKER, 2012; SANTOS-NETO; COSTA, 2019).

In contrast, SISWANTORO et al., (2022) advance to use the clauses of ISO 55001:2014 to propose a new MM for asset-intensive companies. In this sense, a questionnaire is developed

based on ISO 55001:2014 and a self-assessment approach, which is tested to guarantee validity and reliability. An interesting contribution is to use the guidelines proposed in ISO 55002:2014 to establish strategies to improve AM dimensions. Nevertheless, SISWANTORO et al., (2022) do not provide a generic procedure to support the application of AMMM.

WIJNIA, YPE; DE CROON, (2015) also present an AMMM based on ISO 55002:2014 with a focus on risk management. The reference model consists of the AM processes related to capability management, information management, and management review. It is worth noting that the authors do not communicate the AM classes used and the methodologies to measure AM dimensions.

SAM+ proposed by IAM, (2014) elaborates a reference model that can be used by users of ISO 55001:2014 or BSI PAS 2008. The Institute of Asset Management published a system based on Excel to support the application of AMMM. In addition, it makes available materials and guidance to support the assessment of AM maturity. However, there are two challenges in application: the reference model uses all AM dimensions, increasing the complexity of assessment, because 121 questions must be answered; the tools and materials are not freely available, which can hinder the application of SAM+.

ASSET INSTITUTE, (2021) publishes the AMCaMM(Asset Management Capability Maturity Model) to support AM decision-makers in AM maturity assessment, considering thirty questions that reflect AM processes. AMCaMM is available freely in spreadsheet documentation, where the evaluator assesses each question on a 5-level scale and needs to identify the level of completeness to achieve a new level. However, the spreadsheet is focused on a unique evaluator, which can not bring the real level of AM practices (GERSONIUS et al., 2020;LIMA, G. H. de A. L.; COSTA, 2023).

Similarly, STATE OF VICTORIA, (2017) developed the AMAF Maturity Assessment, which is composed of twenty AM dimensions that include reporting to government and evaluation of asset performance. It is worth noting that the AMAF uses two two-scale the system status (describes the presence of evidence in the organization) and the effectiveness of application (describes the extent to which the evidence has been applied in the organization). Moreover, this model provides AM classes and the capabilities of AM dimensions in a chart.

The COMMERCE COMMISSION OF NEW ZEALAND, (2011) developed an AM maturity assessment tool based on IAM. This tool uses thirty questions to assess AM maturity. However, it is not specified the reasons for choosing the quantity that comprises the

questionnaire. Similarly, to occur with AMCaMM there is a lack the integration with multiple assessments. In addition, it does not provide AM classes to guide the organization in continuous improvement.

The FEDERATION OF CANADIAN MUNICIPALITIES, (2018) presents the AMRS (Asset Management Readiness Scale) to support local governments in assessing their AM practices. This AMMM assesses areas related to AM policy, People and Leadership, Information management, AM Planning, and contribution to AM practices. To each AM dimension, there is a scale of 5 levels with evidence to each of them. In this sense, Canadian governments have a tool to assess, focusing on infrastructure assets.

Transit Agency Asset Management Maturity Self-Assessment is an AMMM proposed by FEDERAL TRANSIT ADMINISTRATION, (2017) to promote AM maturity assessment of AM plans that take into account vehicles, equipment, facilities, and infrastructure. In contrast with other AMMMs, the FEDERAL TRANSIT ADMINISTRATION, (2017) establishes instructions and guidelines for organizations to apply its model effectively.

GOVERNMENT PROPERTY PROFESSION, (2014) proposes the Property Asset Management Capability Assessment Model (PAMCAM) assesses AM maturity in AM strategy, AM planning, AM delivery, and AM Operation. An advance in this AMMM is its operationalization in a DSS available online. The DSS allows for storing the progress in the assessment, identifying questions and AM dimensions answered, and controlling the assessment. However, it is only available to government organizations, which restricts its use.

Asset management maturity assessment (AMMA) was developed by OFWAT, (2017), aggregating AM dimensions related to Strategy & planning, Asset information, Decision making, Risk and review, and organization and people. Moreover, it was well-developed five AM classes that described the current stages of asset-intensive industries. It also provides evidence for each question that reflects the evidence of the five AM classes.

The AM Framework was developed for Ontario municipalities to evaluate and develop their asset management planning processes (MFOA, 2018), which consider eleven AM processes. It is relevant to mention that this AMMM proposes a prescriptive approach to assist organizations in implementing roadmaps to AM improvement, which is not present in most AMMMs.

2.2.2.1. AM dimensions

Initially, it is relevant to identify the difference between the AM dimensions that are used in AMMMs. As mentioned, GFMAM (2014) has established 39 AM dimensions (Table 2), which encompass the scope of AM of different models, such as the ISO 5500i series. Considering this, each AMMM was verified for the AM dimension that they cover, which are summarized in Table 4.

Table 4 – Frequency of AM dimensions on AMMMs

GFAM Dimension	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
AM Policy			x	X	x		x		x	x	x	x		x		x	x		x
AM Strategy and Objectives			x		x	x	x		x	x	x	x		x		x	x	x	x
Demand Analysis			x						x					x			x		x
Strategic Planning			x			X		x									x		x
AM Planning			x		x	x	x		x	x	x	x		x	X	x		x	x
Operation & Maintenance Decision-making					x							x						x	x
Resourcing Strategy				X		X		x									X		x
Lifecycle Value Realisation				X			x										X		x
Capital Investment Decision-making			x	X	x				x		x	x				x	x		x
Shutdown & Outage Strategy																			x
Data and Information Management	x	x	x	x		X	x		x	x	x		x	x		x	x	x	x
Asset Information Standards						X		x	x					x					x
Asset Information Strategy				X										x					x
Asset Information Systems			x		x	x	x	x	x			x			x		X	x	x
Asset Creation & Acquisition					x		x	x											x
Asset Decommissioning & Disposal					x		x	x											x
System Engineering																			x
Technical Standards & Legislation															X				x
Configuration Management																			x
Reliability Engineering																			x
Resource Management	x									X	x		x			x			x
Fault & Incident Response						X		x		X								x	x
Asset Operation					x		x												x
Shutdown & Outage Management																			x
Maintenance Delivery			x	X		X	x	x		X					X				x
Procurement and Supply Chain Management			x	X			x			X			x			x			x
AM Leadership	x	x		x	x	x	x	x		X		x		x			X	x	x
Competence Management	x	x	x	x		X	x	x		X	x		x	x	x				x
Organizational Culture	x	x					x								x				x
Organizational Structure				X										x					x
Stakeholder Engagement				X			x							x			X		x
Sustainable Development							x												x
Management of Change				X		X	x			X						x			x

Risk Assessment & Management		x	x		x	x	x	x	x	x			x	x		x	x	x	x
Management Review, Audit & Assurance						x	x	x	x	x			x	x		x			x
Contingency Planning & Resilience Analysis					x			x		x									x
Asset Management System Monitoring																		x	x
Asset Cost & Valuation					x		x	x			x			x			x		x
Asset Performance & Health Monitoring			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Source: This Research (2025).

By analyzing the AMMMs, it is identified that most of them do not use all dimensions. This finding is expected due to organizations prioritizing areas that consider the organizational context (IAM, 2014) and the complexity of performing a maturity assessment involving all dimensions. This point is claimed in MAHMOOD et al., (2015), LIMA, G. H. de A. L.; COSTA (2023) and LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b). Therefore, a useful model should prioritize the core dimensions of AM.

The most frequent AM dimensions in AMMMs are Asset Performance & Health Monitoring, Data & Information Management, Risk Assessment & Management, AM Strategy and Objectives, AM Planning, AM Leadership, Competence Management, AM Policy (LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b). These AM dimensions are related to some core competencies in the AM context, mainly regarding asset information, risk management, and performance evaluation (MALETIČ *et al.*, 2020, 2023).

It is worth noting that in the previous review of AMMMs was identified that the AM dimensions related to people and strategy were overlooked (GFMAM, 2024; MAHMOOD *et al.*, 2015). In contrast with Table 4, it is possible to infer that the current AMMMs have inserted into their reference models these dimensions, which are essential to AM. Consequently, an effective MM for AM needs to incorporate these AM dimensions.

In addition, Asset Performance & Health Monitoring dimension makes a relevant contribution to AM initiatives, incorporating metrics and methodologies to measure risk and performance . These dimensions are related to operational performance, enabling managers to make diverse decisions. Therefore, most AMMMs address AM dimensions to performance and risk competencies.

On the other hand, the dimensions related to lifecycle delivery show an elementary level in most AMMMs, except the maintenance delivery dimension, probably due to the relevance of the maintenance-related activities for AM, such as maintenance strategy and determining the

condition of components (SCHNEIDER *et al.*, 2006). The less cited dimensions rely on AM decision-making, which has demanded new approaches for decision-making based on value and data that incorporate the stakeholders' views (PETCHROMPO; PARLIKAD, 2019).

2.2.2.2. Method of application

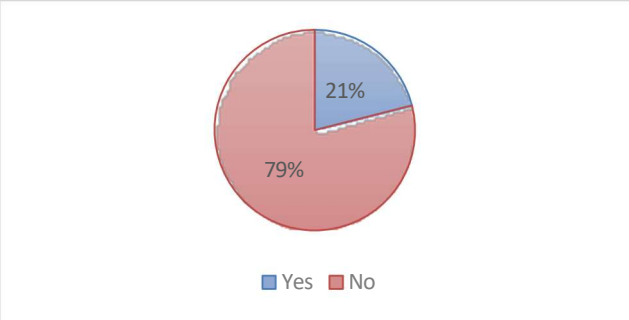
MMs can be applied using self-assessment, third-party assessment, and a certified practitioner (DE BRUIN; HEALTH; ROSEMANN, 2005), as mentioned previously. Most AMMMs have proposed a self-assessment freely. They conduct a self-assessment, collecting the data themselves, following a questionnaire or survey (MAHMOOD *et al.*, 2015). The benefits of the self-assessment process included immediate gains (it facilitates benchmarking and continuous improvement) and long-term gains (it improves business results and provides a disciplined approach to business planning), as claimed by RITCHIE; DALE, (2000). Notably, when the organization applies a self-assessment model, this may improve the learning process (BALBASTRE; LUZÓN, 2003).

The AMMMs proposed by VOLKER et al., (2011) and ABDELHAMID; BESHARA; GHONEIM, (2015) are more adequate to be applied to a third-party, which has expertise around the reference model, as well as has participated in the AM project. In contrast, the self-assessment developed by IAM, (2014) can be used by certified practitioners as part of the certification process in the ISO 55001. For example, the Brazilian Association of Maintenance and Asset Management (Associação Brasileira de manutenção e gestão de ativo) is an institute linked to the IAM and has in the certification process the AM maturity assessment.

However, the element of assessment procedure, which comprises the presence of methodologies that include the steps, methods, requirements, and interplay between their steps, to guide the organization on how to apply the maturity model (PÖPPELBUSS MAXIMILIAN RÖGLINGER, 2011) has received limited attention. Specifically, only 21% of AMMMs have been assisted by a procedure (Figure 6).

Consequently, the process to aggregate data of assessment to assign a maturity class fails. In this way, it is opportune to develop the assessment procedures that support the effective and correct application of AMMMs.

Figure 6 – Frequency of assessment procedure in AMMMs



Source: This Research (2025).

This finding is also found in the MMs field (LACERDA; VON WANGENHEIM, 2018; SANTOS-NETO; COSTA, 2019; TARHAN; TURETKEN; REIJERS, 2016). This may be the fruit of a misunderstanding between the concepts of the maturity model (reference model) and the assessment procedure, which are seen as identical concepts (TARHAN; TURETKEN; REIJERS, 2016). Though there are reasons for this lack, the result is that the absence of procedures may hinder the MM application (SANTOS-NETO; COSTA, 2019), and consequently, the assignment of AM maturity classes in the maturity assessment.

2.2.2.3. AM classes

Maturity class, as described previously, is a label that reflects their intent, which is complemented by definitions summarizing key requirements, measures, and new elements not present in earlier stages (PAULK *et al.*, 1993). Unfortunately, it does not have a methodology to provide a step-by-step guide to develop the maturity classes. Consequently, it does not have a unique definition, including in the same field.

Table 5 summarizes the AM classes provided by 19 AMMMs found. As can be seen, it does not have a unique set of AM classes, which collaborates with GFMAM, (2021) that highlights different maturity classes in the AM context. However, it is possible to identify some standards:

- Most of them have five or six AM classes. Consequently, this suggests that an adequate number of levels may be five or six.
- Typically, the range extends from the complete absence of evidence of AM processes to the full achievement of excellence in their implementation.

- Most of them fail to provide a clear description of the label, that is, they do not describe the main characteristics of each AM maturity class.

Table 5 – AM Classes in AMMMs

AMMM Code	AM Classes	AMMM Code	AM Classes
1	Optimised Well managed Standardised Repeatable Ad hoc	9	Aware Basic Core Intermediate Advanced
2	Initial Repeatable Defined Managed Optimizing	10	5 levels, without labels
3	Unaware: Aware: Application: Systematic Approach: Competence: Excellence:	11	6 levels, without labels
4	Incomplete Initial Managed Defined Quantitatively managed Optimized	12	5 levels, without labels
5	5 levels, without labels	14	Unaware. Aware Developing Competent Optimising
6	Innocent Aware Developing Competent Beyond Beyond	15	5 levels, without labels
7	Reflects current state Developing Well progressed Advanced	17	Basic Intermediate Advanced
8	Not Applicable Innocence Awareness Developing Competence Optimising	19	Innocent Aware Developing Competent Optimising Excellent

Source: This Research (2025).

2.2.2.4. AMMM Application

Broadly speaking, MMs have had a predominantly descriptive focus (SANTOS-NETO; COSTA, 2019; TARHAN; TURETKEN; REIJERS, 2016), which has occurred similarly in the AM context. Most AMMMs seek to develop a model that determines the current stage of AM maturity, except the model developed by SISWANTORO et al., (2022), which provides insights into the prescriptive approach. So, what stands out is the absence of prescriptive models, which could suggest paths to improve the AM processes.

DE BRUIN; HEALTH; ROSEMANN, (2005) highlights that the descriptive, benchmarking, and prescriptive approaches of the applications are related. In the beginning, a descriptive model emerges to assess specific capabilities. With wise use in the field, it is possible to infer about the best practices, enabling the development of a benchmarking approach. Finally, the consolidation of MM and the broad knowledge is likely to propose a prescriptive model.

Since AM maturity assessments demand multiple evaluations and thorough preparation, most AMMMs rely on textual documentation or Excel-based tools. In contrast, only two (GOVERNMENT PROPERTY PROFESSION, 2014; IAM, 2014) are supported by DSS, which, as noted, have limited accessibility.

The DSS provided by GOVERNMENT PROPERTY PROFESSION, (2014) is available only for members of government, whereas IAM, (2014) is made available through the association, which is paid annually, and it needs to buy for textual guidance to understand all dimensions involved on its AMMM. Therefore, developing a comprehensive descriptive maturity model that integrates key foundational elements to ensure replicability remains essential.

2.3. AM and Business Performance

In this section, evidence from AM literature is explored that enables the development of hypotheses that demonstrate some relationship between AM maturity, business performance, and AM competencies. These hypotheses will be the object of statistical tests to reveal the role of AM maturity on business performance.

2.3.1. Business Performance nature

The competitive strategy field has organizational performance as a core theme, which aggregates essential elements for business, such as sustainability and social (ZAIRBANI; JAYA PRAKASH, 2025). The organizational strategies guide to development of the organizational objectives. Organizational objectives are specific and measurable propositions about tasks, activities, and processes that must be undertaken to meet its major targets, which include respecting its ideals and the organization's main accomplishments (BARBER; TAYLOR, 1990).

Relevant organizational objectives are derived from stakeholders' points of view, so there is a need to balance internal and external stakeholders' requirements for corporate strategy. Therefore, when the organization achieves these objectives, it creates value for its stakeholders (ISO, 2014). Thus, business performance is a multidimensional dominion that considers internal and external requirements.

In this aspect, organizations develop operational strategies that take into account their competitive priorities, such as quality, flexibility, and cost to increase business competitiveness, and strive to align organizational capabilities to achieve these priorities (BOYER; LEWIS, 2002; ZAIRBANI; JAYA PRAKASH, 2025). In this regard, assets play a role in organizational competitiveness and growth (SMITH; SHARIF, 2007), impacting the competitive priorities related to flexibility and delivery, and assets also play a role in the operating frontier (CAI; YANG, 2014).

In this context, business performance management allows an organization to implement and monitor strategic initiatives, which makes it possible to develop corrective action so as to improve business performance (FROLICK; ARIYACHANDRA, 2006). The aim is to monitor and measure the business performance indicators that are used. These are quantitative or qualitative metrics that measure the stage of the organization, and they should reflect the organizational objectives and goals (POPOVA; SHARPANSKYKH, 2010; VAN LOOY; SHAFAGATOVA, 2016).

Whereas at the beginning of business performance there was a focus on financial indicators, currently organizations have incorporated nonfinancial indicators, which include new demands such as sustainability (BITITCI, UMIT *et al.*, 2011). In addition, asset performance indicators have been implemented in organizations to measure the life cycle of

assets (PARIDA, 2012). So, business performance needs to be measured by performance indicators that come from multiple areas of organizational objectives.

In this context, SIEMIENIUCH; SINCLAIR, (2002) confirm that the organizational environment is a complex variable, composed of the interaction of organizational components, including people, processes, assets, and systems. Consequently, business performance emerges as a hard metric to measure. However, as mentioned in subsection 2.1.3, there are challenges related to data quality and collection. Considering this landscape, researchers in different journals have investigated organizational capabilities that can explain business performance variance.

By investigating the effects of resource human management on business performance, FERGUSON; REIO, (2010) find that the use of human resource practices influences business performance. Similarly, PAVLOV et al., (2017) investigate the role of human resource management and performance management on business performance, discovering that practices related to Commitment-based reward practices have an impact on business performance.

A strategic resource for an organization is the manner in which it manages its information technology. Due to this relevance, some studies have investigated the role of managerial capabilities of information technology on business performance, finding a positive association between information technology and business performance (JEYARAJ; SABHERWAL, 2015; MITHAS; RAMASUBBU; SAMBAMURTHY, 2011; MITHAS; RUST, 2016; OH; YANG; KIM, 2014). In this context, capabilities related to e-business (YANG *et al.*, 2010), e-procurement (OH; YANG; KIM, 2014), and information technology (CHEGE; WANG; SUNTU, 2020) influence business performance.

Finally, recent studies seek to explore new trends in organizational strategies. Considering the environmental perspective, enterprises that invest in environmental practices can achieve better returns in firm performance, which encompasses environmental, financial, and non-financial performance (ILIOPOULOU; VLACHVEI; KORONAKI, 2024; LUNDGREN; ZHOU, 2017; RAUNIAR; CAO, 2025). On the other hand, the capabilities to manage innovation are correlated with firm performance (GARRIDO-MORENO; MARTÍN-ROJAS; GARCÍA-MORALES, 2024), for example, green innovation and disruptive innovation affect the performance (DENG *et al.*, 2025; WANG, CHENXIAO; GUO; ZHANG, 2023).

In addition, various factors have been found to influence business performance. These include the company's age and size, its status regarding foreign ownership and use of foreign technology, the skill level of its production workforce, access to diverse sources of funding, the accuracy of its strategic resources, and the adequacy of its human resources (ANDERSÉN, 2011; FERGUSON; REIO, 2010; OKAFOR, 2017)

Considering this context, adopting a pre-set approach to predict business performance appears to be inadequate. Thus, it is relevant to explore the ability of elements of the organizational system to promote business performance, which includes asset management. However, few researchers have investigated and validated the relationship between organizational maturity and business performance.

2.3.2. AM Maturity

As mentioned, the relationship between organizational maturity and business performance has been the subject of a few studies (TARHAN; TURETKEN; REIJERS, 2016), which includes the link between AM maturity and business performance. This information turns useful in a context where it has demand for decision-making based on value and data(PETCHROMPO; PARLIKAD, 2019) . Therefore, AM maturity and business performance must be investigated (HAN *et al.*, 2021; LIMA, ELIANA SANGREMAN; MCMAHON; COSTA, 2021)

Although the direct effect of AM maturity on business performance has yet to be empirically uncovered, previous studies have shown that core AM dimensions influence operational performance (HAN *et al.*, 2021; MALETIČ *et al.*, 2018, 2020). In this sense, these studies suggest that AM maturity may affect business performance. Therefore, the following hypothesis is proposed:

H_1 : AM maturity has a positive effect on business performance.

It is worth noting that the AM competencies presented below correspond to the AM groups shown in Table 2, which are measured by the AM dimensions proposed in the reference model. For example, Strategic AM competence corresponds to Strategic and Planning group, which is measured by AM Policy, AM Strategy and Objectives, and AM Planning.

2.3.3. Strategic AM competence

As mentioned, Strategic AM competence is essential in AM due to assets are critical to asset-intensive organizations since their contributions affect organizational objectives such as

profitability and availability (AMADI-ECHENDU, 2004; ISO, 2024a; SCHUMAN; BRENT, 2005). In this sense, strategic AM competence is composed of AM Policy, AM Strategy and Objectives, and AM Planning, which are responsible for determining the AM systems, AM objectives, AM strategies, and AM plans to achieve organizational objectives using assets.

In this strategic scope, BRITTON; RUMSEY, (1990) claim that an effective AM plan must include some elements:

- Guidelines for the development and periodic revision of the asset management plan.
- A declaration of the applicable policies and standards.
- An inventory of asset systems, which must include the assets operating in the organization.
- Data regarding the condition and performance of the main elements within each system.
- Forecasts of long-term investment needs—covering approximately a 20-year horizon—to address performance and condition gaps as well as to accommodate future demand and expansion; and
- A short-term investment plan, detailing projects in alignment with long-term planning.

In view of these elements, it is evident that the Strategic AM competencies influence other AM dimensions. For example, considering the six elements of Britton and Rumsey's framework, there is a connection between Strategic AM competencies, Asset information competencies, and Risk and Review competencies. Therefore, the level of strategic AM of the organization can contribute to the level of managerial and operational AM dimensions

Complementing this perspective, EL-AKRUTI; DWIGHT; ZHANG, (2013) propose a framework to support the establishment of an AM strategy, which connects AM activities and strategic development. In this context, AM activities demand the support technique, which is composed of leadership and people management that are central to AM. Thus, Leadership & People competencies, in this thesis are related to AM Leadership and competence management are set in the AM planning (GFMAM, 2024).

In another research, BROWN et al., (2014) propose that to achieve a strategic AM the enterprises need to consider the development of risk management, performance management, competence management, and information systems. Therefore, strategic competence aims to build organizational resources through assets to improve results, which is expected to positively influence other AM competencies:

H_2 : Strategy competence has a positive effect on AM Maturity.

H_3 : Strategy competence has a positive effect on Risk & Review.

H_4 : Strategy competence has a positive effect on Leadership & People.

H_5 : Strategy competence has a positive effect on Asset Information.

2.3.4. Asset Information

Asset Information competencies are essential to the AM context (BRYCE, 2024; IAM, 2024; OUERTANI; PARLIKAD; MCFARLANE, 2008; POLENGHI *et al.*, 2022), which support the decision-making in AM activities. Asset Information competence refers to data governance and the use of information systems to support AM, which must be developed across the organization (POLENGHI *et al.*, 2022) As AM integrates multiple areas with rules, procedures, and information specifics, it demands an approach based on systems.

Thus, the asset information system sustains AM processes by collecting, managing, and sharing organizational data and by enabling coordination across departments (GFMAM, 2024; IAM, 2024). Incorporating solutions based on information systems brings organizational results, such as ensuring timely and complete deliveries, facilitating the planning of e-business systems, managing the interactions between information technology and operations management, and providing support for the decision-making process (CHANG, 2006). However, as mentioned, there are many AM challenges related to asset data (ISO, 2024a), which contribute to the loss of information.

In order to reduce the effects of the loss of information, mainly due to data aggregation in the index, frameworks to manage and use data in decision-making are essential (BRYCE, 2024). In this scenario, the capabilities related to leadership and people may contribute to the effectiveness of asset information capabilities. By investigating information technology literature, it is found that the capabilities to manage people influence other organizational capabilities, including capabilities related to information technology/system (AYDINER *et al.*, 2019; CHANG, 2006; MITHAS; RAMASUBBU; SAMBAMURTHY, 2011).

Therefore, the following hypotheses are drawn up

H_6 : Asset Information competence has a positive effect on AM Maturity.

H_7 : Leadership & People competence has a positive effect on Asset Information.

2.3.5. Leadership & People

Within the AM context, ISO, (2024b) has introduced a new standard, ISO 55012, which offers guidance for enhancing the engagement, contribution, and commitment of an organisation's human resources toward achieving AM objectives. This documentation reinforces the role of Leadership & People competencies for AM , which is aligned with the relevance of leadership and competence management in providing direction to the business (LIU *et al.*, 2023; MAI; DO; HO NGUYEN, 2022).

Consequently, the competence of Leadership & People is anticipated to influence AM Maturity. Then, we have the following hypothesis:

H_8 : Leadership & People competence has a positive effect on AM Maturity.

2.3.6. Risk and Review

Performance and risk management are trending topics in AM, mainly in AMMMs, demonstrating the potential to contribute to delivering value as the enterprises develop these competencies. Risk & Review competence consists of the dimensions of Risk Assessment and Management, Asset Performance and Health Monitoring, and Asset Costing and Valuation, which are essential to the effectiveness of the AM systems (IAM, 2008; ISO, 2024a).

However, Risk and Review capabilities demand the modelling of scenarios using data, which faces challenges due to the lack of suitable data (BERTRAND *et al.*, 2024). In addition, the capabilities to risk and review have demanded good practices in data management, leadership, monitoring of indicators, and commitment (FROLICK; ARIYACHANDRA, 2006; ROBINSON *et al.*, 2005). Therefore, we have the following hypothesis:

H_9 : Risk & Review competence has a positive effect on AM Maturity.

H_{10} : Asset Information competence has a positive effect on Risk & Review competence.

H_{11} : Leadership & People competence has a positive effect on Risk & Review competence.

Table 6 summarizes the hypotheses drawn.

Table 6 - Hypotheses developed

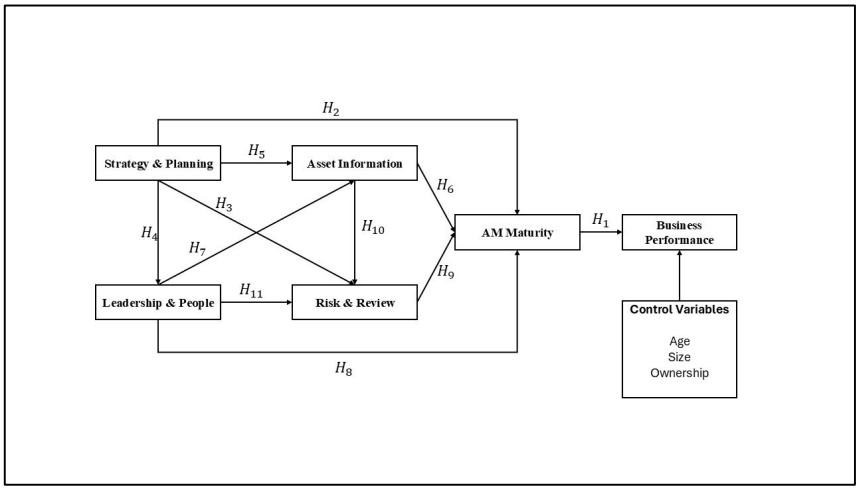
Hyphotesis	Reference
H_1: AM maturity has a positive effect on business performance	HAN et al., (2021), MALETIČ et al., (2020), and MALETIČ et al., (2018)

H_2 : Strategy & Planning competence has a positive effect on AM Maturity	EL-AKRUTI; DWIGHT; ZHANG, (2013) and IAM, (2024)
H_3 : Strategy & Planning competence has a positive effect on Risk & Review.	BRITTON; RUMSEY, (1990) and BROWN et al., (2014)
H_4 : Strategy & Planning competence has a positive effect on Leadership & People.	(EL-AKRUTI; DWIGHT; ZHANG, 2013) BROWN et al., (2014)
H_5 : Strategy & Planning competence has a positive effect on Asset Information.	BRITTON; RUMSEY, (1990) and BROWN et al., (2014)
H_6 : Asset Information competence has a positive effect on AM Maturity.	(IAM, 2024)
H_7 : Leadership & People competence has a positive effect on Asset Information.	(MITHAS; RAMASUBBU; SAMBAMURTHY, 2011) (CHANG, 2006)
H_8 : Leadership & People competence has a positive effect on AM Maturity.	ISO (2024b), IAM, (2024)
H_9 : Risk & Review competence has a positive effect on AM Maturity.	IAM, (2024)
H_{10} : Asset Information competence has a positive effect on Risk & Review competence	(BERTRAND *et al.*, 2024)
H_{11} : Leadership & People competence has a positive effect on Risk & Review competence.	(FROLICK; ARIYACHANDRA, 2006; ROBINSON *et al.*, 2005)

Source: This Research (2025).

A structural model (Figure 7) was developed based on these hypotheses and is intended to be tested using the PLS-SEM methodology.

Figure 7 – Structured theoretical model



Source: This Research (2025).

3 METHODOLOGY

3.1. Developing AMMM and Assessment procedure

As mentioned, many MMs do not provide elements that describe the methodology used in the development step. In order to overcome this challenge, the framework to build a MM proposed by DE BRUIN; HEALTH; ROSEMANN, (2005) is adopted, which is based on six phases, namely scope, design, populate, test, deploy, and maintain. This framework has been used in diverse applications, such as digital transformation maturity (GÖKALP; MARTINEZ, 2022), Industry 4.0 maturity (P. SENNA *et al.*, 2023), Big data maturity (COMUZZI; PATEL, 2016), and supply chain maturity (ASDECKER; FELCH, 2018).

Initially, the scope of AMMM is defined, establishing the boundaries of AMMM, their context, and use, as well as the stakeholders involved in the development of AMMM. Considering this, the reference model proposed is designed to provide asset-intensive industries with a descriptive model that allows an assessment of current AM practices. To achieve this scope, academic and practitioner professionals are involved in the development.

With the scope defined, the design step focuses on defining the technical specifications of AMMM, that is, the audience, method of application, driver of application, respondents, and application are determined. It is worth noting that in the design phase is defined whether the application will be made by third parties, certified practitioners or self-assessment. In light of the AM context and the recognized benefits of self-assessment, the model is intended to support the self-assessment application.

The next step is the populate phase, which aims to address two main questions: what should be measured and how it should be measured. Answering the first question, key constructs related to AM maturity were identified through a literature review and the analysis of enterprise reports. The 40 AM dimensions provided by GFMAM, (2024) can be used as AM constructs, however, as mentioned, using all dimensions may make the application difficult. Therefore, for this, the dimensions most cited (Table 4) in the literature review and enterprise reports (LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b).

Yet in the populate phase, it is need to define the questions to measure each construct, which is essential in balancing the number of questions. Besides, to guarantee truthfulness, at least three questions per dimension are required (QUINLAN *et al.*, 2015), and approximately 30 questions are adequate (IAM, 2014). So, the set of questions (Appendix B) was selected and adapted from the literature review and enterprise reports.

The test phase is dedicated to assessing whether the developed data collection instrument accurately captures the constructs designed to evaluate AM maturity. This process involves the use of established methods and techniques to ensure measurement validity (BAGNI *et al.*, 2024). However, there is a lack of a validation process in most MMs (SANTOS-NETO; COSTA, 2019). The test was performed in two stages. First, two experts who work in AM practices were interviewed individually around the initial version of AMMM. As a result, the asset costing and valuation dimension was added. Afterward, twelve case studies were undertaken with the aim of verifying whether the AMMM proposed is useful to assess AM maturity.

Once the MM achieves the populate and test phases, the model is available for use in order to verify the generalizability. In addition, to the companies that applied it in the testing phase, dozens of other asset-intensive enterprises have used it and provided positive feedback. As a result, the AMMM proposed have achieve generalizability in the AM context.

Finally, the last phase seeks to provide evolution to AMMM. In this case, the procedure and system proposed offer a means to maintain and update the reference model proposed. Table 7 illustrates the application of the framework.

Table 7 - summarizes the application of the DE BRUIN; HEALTH; ROSEMANN, (2005) framework.

Phase	**Characteristics of MM**	**Characteristics of AMMM**
Phase Scope	Focus	Asset-intensive industries
	Purpose	Descriptive
	Development stakeholders	Academia
Design	Method of application	Self-assessment
	Audience	Internal
	Respondent	Employees with AM Knowledge
	Maturity stages (classes)	Not applied Aware Developing Competence Optimizing Excellent
Populate	Domains (dimension or key process areas)	AM process most cited in available AMMM Interviews

	Instrument	Questionnaire based on the literature
Test	Characteristic	Validity Reliability
Deploy	Characteristic	Generalizability
Maintain	Instrument	Procedure and DSS

Source: adapted from LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b)

As mentioned, the development of AMMM is not enough to guarantee the correct application. Then, a procedure assessment for applying the AMMM is presented. For the construction of the procedure assessment, design science research was adopted.

The design science research is an approach that enables the solution of organizational problems through the creation of artefacts, such as methods, constructs, models, and instantiations, which can have both an academic and practitioner focus (BAGNI *et al.*, 2024; HEVNER *et al.*, 2004). Specially, PEFFERS et al., (2007) propose the six design science research activities, namely identification of the problem, defining objectives of the solution, design, demonstration, evaluation, and communication. These guidelines are essential in design science research, which able organizations and researchers to develop a new solution.

The methodology begins with the identification of an organizational problem. By analyzing the AM literature, it is possible to highlight the lack of a procedure assessment that guides the application of MM, which can hinder the application in organizational practice. Consequently, the problem is the absence of procedure assessment in the AMMM field. In order to solve this, the *defining objectives of the solution* stage demand the establishment of qualitative or quantitative objectives that describe a mental model or descriptive template related to the knowledge of stage of problem and potential solution. In this scenario, the procedure assessment must guide the correct and effective application of the AMMM proposed, using methods and requirements for the self-assessment methodology.

The third element is the design, which comprises the Development of the Methodology, in this thesis, a procedure assessment. Considering the self-assessment approach and the descriptive purpose of AMMM proposed, the procedure assessment must contain the following stages (LIMA, G. H. de A.; COSTA, 2025a;LIMA, G. H. de A. L.; COSTA, 2023):

- Planning.
- Making the assessment.

- Knowledge aggregation.
- Determining the maturity level.
- Supporting decision-making.

It is worth noting that different methodologies and methods were proposed to support each phase of the reference model, ensuring its proper application. For example, knowledge aggregation demands some statistical methodologies. In addition, the nature of these steps and their requirements, a decision support system (DSS) was developed to operationalize this assessment procedure.

Considering the characteristics required for the assessment procedure, such as multiple users to make the assessment, a self-assessment approach, and anonymity, an architecture based on web DSS was chosen. ZAHEDI; SONG; JARUPATHIRUN, (2008) emphasizes that web DSS has the following characteristics, which are fitted with the assessment procedure:

- Accessible through the Web, which supports individuals, customers, employees, managers, and groups in their decision-making processes, independent of their physical location or time of access.
- Producing outcomes tailored to a predetermined context.
- Addressing semi-structured and unstructured decision processes across different stages, which must address privacy concerns and assurance regarding the protection of personal information.
- Leveraging data, knowledge bases, documents, models, and heuristics to serve a culturally diverse and broad user group.
- Serving as an optional tool to assist Web users in their decision-making activities, which must be designed to minimize the need for training.

Subsection 4.2 provides deep explanations about each stage of the procedure assessment and the DSS.

With the artefact already, the demonstration stage begins. The aim of this stage is to provide a demonstration of the procedure assessment of the target group, in our context, asset-intensive companies. In this sense, twelve real applications were performed in asset-intensive enterprises to demonstrate the contribution of the AMMM application. Similar to the AMMM proposed, the evaluation was performed by two experts, and the real application that provided feedback on the usability and accuracy of the procedure assessment.

Finally, the assessment procedure and DSS have been divulged in industrial enterprises and managers and professionals enrolled in programs related to AM, such as production engineering and maintenance engineering, concluding the communication stage.

3.1.1 Data collection and sample

In order to improve the usability of AMAP, it was necessary to develop a strategy to reach asset-intensive industries. So, to attain this target group, managers and professionals enrolled in educational programs focused on AM were invited to try AMAP and provide feedback.

The purpose is to assess the effectiveness of AMAP in assigning AM classes that correspond to organizational practices. So, feedback could be provided through meetings or reports, which should include assessments or evidence regarding the alignment between the AM class designated by AMAP and the existing AM practices, as well as an explanation of the organization's intended actions based on the outcomes obtained.

Applying the strategy, twenty Brazilian asset-intensive Brazilian enterprises provided evidence and feedback during the AMAP application. To ensure anonymity, these enterprises were encoded as E1 – E20. The requirements of the assessment team are provided in the assessment procedure proposed in subsection 4.2. Table 8 summarizes the profiles of the sample.

Table 8 – Profiles of asset-intensive enterprises

Enterprise	**Business sector**	**Multinational**	**Nº Employees**	**Size**
E1	Automobile	X	2500	Large
E2	Automobile	X	6000	Large
E3	Manufacturing		700	Large
E4	Manufacturing and electrical power transmission	X	800	Large
E5	Manufacturing	X	814	Large
E6	Infrastructure		6199	Large

E7	Manufacturing		50	Medium-large
E8	Manufacturing	X	500	Large
E9	Electrical power		90	
E10	Manufacturing and retail	X	50-200	Medium
E11	Telecommunication		17	Small
E12	Manufacturing	X	700	Large
E13	Electrical power transmission		3000	Large
E14	Manufacturing	X	300	Large
E15	Manufacturing	X	unauthorized	Large
E16	IT	X	2500	Large
E17	Public sector		1004	Large
E18	Mining	X	unauthorized	Large
E19	Manufacturing	X	8000	Large
E20	Mining	X	6000	Large

Source: This Research (2025).

3.2. Developing the relational study between AM Maturity and Business performance

3.2.1 PLS-SEM

Multivariate methods are statistical tools that enable the identification of the relationship between multiple variables, which use data collected in surveys or observations. HAIR, JOSEPH F.. et al., (2017) highlighted that multivariate methods can be classified with regard to the focus (confirmatory or exploratory research) and the generation, which are presented in Table 9. Therefore, there are different methods available to exploit the relationship between AM maturity and Business performance. So, it is relevant to find a method more adequate to the research and data available in this research.

Table 9 – Classification of Multivariate methods

	Primarily Exploratory	**Primarily Confirmatory**
First-generation techniques	- Cluster analysis - Exploratory factor analysis - Multidimensional scaling	- Analysis of variance - Logistic regression - Multiple regression - Confirmatory factor analysis
Second-generation techniques	- Partial least squares structural equation modeling (PLS-SEM)	- Covariance-based structural equation modeling (CB-SEM)

Source: Adapted from HAIR, JOSEPH F.. et al., (2017)

In contrast to other multivariate approaches, structural equation modeling (SEM) provides the ability to include latent constructs, which represent abstract concepts that are not directly observable and are instead inferred from their underlying indicator variables (DASH; PAUL, 2021; HAIR, JOE F. *et al.*, 2014). In this sense, AM Maturity, AM dimensions, AM competencies, and business performance set variables that are abstracted and non-observable directly, which need to be measured based on other variables. Therefore, PLS approaches may be adequate considering this aspect.

Traditionally, the meaning difference among the PLS methods is in terms of the focus. They are confirmatory when testing hypotheses derived from existing theories, and exploratory when identifying patterns in cases of limited prior knowledge about variable relationships. In addition, CB-SEM has some assumptions that limit its application (HAIR, JOSEPH F. *et al.*, 2019)

However, issues to be solved by PLS methods must fit some requirements, mainly around data characteristics. PLS-SEM is particularly suitable in situations such as (HAIR, JOSEPH F. *et al.*, 2019):

- When the goal is to test a theoretical framework from a predictive perspective (focus on an exploratory approach).
- When the structural model is complex, involving numerous constructs, indicators, or relationships.
- When the research seeks to address increasing complexity by extending established theories (exploratory theory development).
- When the model includes formatively measured constructs.
- When using financial ratios or similar types of data artifacts.

- When relying on secondary or archival data that may not be fully supported by measurement theory.
- When small populations limit sample size, although PLS-SEM is equally effective with large samples.
- When data distribution poses challenges, such as non-normality.
- When latent variable scores are required for subsequent analyses.

Taking into account the data, the aim of this research is to explore the relationship between AM maturity and business performance, and the benefits of PLS-SEM in contrast with CB-SEM, PLS-SEM approach has been chosen to measure the effect of AM initiative on performance. Albeit some papers try to argue the inadequacy of SEM applications Rönkkö et al. (2016), papers collaborate on the usability of PLS-SEM, since the requirements are fulfilled (SARSTEDT; HAIR; RINGLE, 2023; SARSTEDT; RINGLE; HAIR, 2014).

By stating PLS-SEM application, the constructs that are the non-observable variables and their indicators must be established. In this thesis, the AM maturity comes from AM dimensions, being aggregated to form the maturity level following the aggregation process present in subsection 4.2.4.. In this perspective, AM maturity is single-item measures, which is necessary to realize the redundancy analysis (CHEAH *et al.*, 2018). In addition, these AM dimensions can be categorized into four intrinsic competencies, as presented previously. So, the constructs in the measurement model are formed by the AM dimensions. Table 10 provides a summary of the indicators for each latent variable associated with AM dimensions.

Table 10 - Composition of latent variables related to AM dimensions

Latent Variable (core competence)	**Dimension/indicator**
Strategy & Planning	AM Policy
	AM Strategy and Objectives
	AM Planning
Asset Information	Data and Information Management
	Asset information Systems
Leadership & People	AM Leadership
	Competence management
Risk & Review	Risk Assessment and Management
	Asset performance and health monitoring
	Asset Costing and Valuation

Source: This Research (2025).

As mentioned, the business performance nature integrates a holistic perspective. Consequently, the metrics used to measure business performance must reflect this whole view. Although business performance can be evaluated using performance indicators (VAN LOOY; SHAFAGATOVA, 2016), it was decided to use a 5-point Likert scale that reflects the business performance trend in a non-evasive way. This approach has been adopted in similar research that tries to identify the drivers of business performance (HAN et al., 2021;HUANG et al., 2025;MAIGA; NILSSON; AX, 2015;MALETIČ et al., 2018a; 2020;WEI; SONG; WANG, 2017).

This methodological strategy allows for the expansion of possible responses, as in a competitive environment, business metrics provide essential information that can not be disclosed to competitors. So, to each question, the enterprise must choose between strongly agree, agree, neutral, disagree, strongly disagree, or I do not know how to answer (whether the person responsible for subscription in the DSS does not have confidence in assigning the option more adequately).

In light of this, by analyzing AM literature, ten questions were selected from the literature with the aim of capturing the landscape of business performance (HAN *et al.*, 2021; MALETIČ *et al.*, 2018, 2020), which were encoded as B1 – B10. Table 11 summarizes the questionnaire and competitive priorities related to the questions. In addition, it stands out that control variables were used, namely, age, ownership, and size, which allow identification of other factors that have contributed to business performance.

Table 11 – Composition of latent variables related to Business Performance

Latent Variable (core competence)	**Dimension/indicator**
Business Performance	BP1 - Has Return on Assets (ROA) increased above the industry average during the last 3 years?
	BP2 - Has the average lead time (from order to delivery) decreased during the last 3 years?
	BP3 - Has market share increased during the last 3 years?
	BP4 - Has on-time delivery performance improved during the last 3 years?
	BP5 - Has the Unit cost of manufacturing decreased during the last 3 years?
	BP6 - Has the improvement in product customization and reliability increased during the last 3 years?
	BP7 - Has the consumption of resources decreased in the last 3 years?

	BP8 - Has the return on investment (ROI) increased above the industry average during the last 3 years?
	BP9 - Has sales growth increased above the industry average during the last 3 years?
	BP10 - Has the growth in profit growth increased above industry average during the last 3 years?

Source: adapted from HAN et al., (2021), MALETIČ et al., (2020) and MALETIČ et al., (2018).

Before applying PLS-SEM, it is required to perform some statical analyses to guarantee the adequacy of constructs and indicators. With the latent variables and their indicators proposed, it is necessary to assess the reliability and validity of the constructs (DASH; PAUL, 2021). For this, initially, the outer loadings are measured, which must be above the threshold of 0.708. Table 12 presents the outer loadings for AM constructs, which achieved a score above the threshold. Therefore, this suggests that the construct explains more than 50% of the variance of the indicator, thereby ensuring an acceptable level of item reliability.

Table 12 - Outer loading results

Constructs	Indicators	Outer Loading
Strategy G Planning	AM policy	0.933
	AM Strategy and Objective	0.969
	AM Planning	0.942
Asset Information	Data and Information Management	0.976
	Asset Management System	0.977
Leadership G People	AM Leadership	0.958
	Competence Management	0.959
Risk G Review	Asset Performance and Healthy Monitoring	0.961
	Risk management	0.959
	Asset Costing and Valuation	0.953

Source: This Research (2025).

Proceeding in outer loadings analysis, Table 13 summarizes the results for business performance. As can be seen, the items BP2, BP4, BP5, and BP6 do not overcome the thresholder, which would be needed to exclude them as indicators. However, HAIR, JOSEPH F.. et al., (2017) explain that before excluding an indicator is adequate to follow this protocol: if the outer loadings indicators are above 0.4, it can be determined whether the deletion of the indicator reduces the AVE metric or improves it. Case the deletion reduces the AVE metric, the indicator can be maintained.

Applying this protocol, deleting the items BP2, BP4, BP5, and BP6 would not result in an increase of reliability, on the contrary these deletions would reduce the metrics. Therefore, these questions have been maintained to measure business performance.

Table 13 – Outer loading results to Business Performance

Constructs	Indicators	Outer Loading
Business Performance	BP1	0.729
	BP2	0.568
	BP3	0.704
	BP4	0.576
	BP5	0.623
	BP6	0.686
	BP7	0.729
	BP8	0.870
	BP9	0.767
	BP10	0.793

Source: This Research (2025). Note: P-value < 0.01

The next step is assessing internal consistency reliability (HAIR, JOSEPH F. *et al.*, 2019). For this, Cronbach's alpha indicator was adopted, for which a value above 0.6 is considered acceptable no exploratory research. In light of this, Table 14 shows the results for each construct in Cronbach's alpha, demonstrating that the constructs are satisfactory.

The third step in assessing the reflective measurement model concerns the evaluation of convergent validity, which reflects the extent to which a construct consistently accounts for the variance of its associated indicator. Specifically, it used the AVE indicator to measure convergent validity (Table 14), where the threshold is above 0.5. All constructs attained the AVE threshold.

Table 14 – Construct Reliability and Validity

	Cronbach's alpha	AVE
Business Performance	0.889	0.505
Asset Information	0.951	0.954
Leadership G People	0.911	0.919
Risk G Review	0.955	0.917
Strategy G Planning	0.944	0.899

Source: This Research (2025). Note: p-value<0.5

An important step in the measurement model is to assess discriminant validity, which refers to the degree to which a construct differs from other constructs, demonstrating its distinctiveness (HAIR, JOSEPH F.. *et al.*, 2017). The Fornell-Larcker criterion is applied for this purpose; it involves comparing the square root of the AVE, found on the diagonal, with the latent variable (FORNELL; LARCKER, 1981), as shown in Table 15. Based on this analysis, discriminant validity was observed.

Table 15 – Discriminant Validity

	Business Performance	Asset Information	Leadership & People	Risk & Review	Strategy & Planning
Business Performance	**0.710**				
Asset Information	0.360	**0.G77**			
Leadership & People	0.335	0.875	**0.G58**		
Risk & Review	0.382	0.910	0.914	**0.G57**	
Strategy & Planning	0.417	0.916	0.891	0.900	**0.G48**

Source: This Research (2025). Note: For any latent variable, the square root of the AVE should be greater than its correlation with any other latent variable.

Because AM Maturity is measured using a single item in a formative manner, discriminant validity cannot be used to assess the model (Joseph F. Hair et al., 2017). Instead, redundancy analysis is conducted, which involves constructing another model and developing

a latent variable with multiple items that represent the same concept as other constructs based on the unique item to evaluate convergence. This analysis confirms an R-squared value of 0.999 and a path coefficient of 1, both exceeding the threshold of 0.7, indicating convergent validity (CHEAH *et al.*, 2018; HAIR, JOSEPH F.. *et al.*, 2017).

Then, the structural model presented in Figure 7 can be assessed, applying PLS-SEM. The results are presented in Section 5.2.

3.2.2 Data Collection and sample

Similarly to the strategy adopted to validate AMAP, managers and professionals were invited to assess the AM Maturity in their enterprise. In contrast with the first applications, it was added to AMAP a questionnaire to assess the business performance (Table 11). The profiles of the seventy enterprises are presented in Table 16. It is worth noting that the twenty enterprises of initial step of this thesis were not considered in the PLS-SEM application.

Table 16 – Profiles of the Enterprise profiles

Ownership		**%**
Private	58	82,9
Public	5	7,1
Foreign	4	5,7
Other	3	4,3
Age		
1 - 2 years	3	4,3
3 - 5 years	7	10
5 - 10 years	5	7,1
10 - 20 years	14	20
More than 20 years	41	58,6
Employees		
Up to 200	25	35,7
200 – 500	10	14,3
500-5000	18	25,7
5000-10000	10	14,3
More than 10000	7	10
Branch		
Manufacturing	20	28,6
Agriculture	5	7,1
Energy	4	5,7
Public sector	4	5,7
Transportation	6	8,6
Other	9	12,9
Mining	5	7,1
Professional Services	7	10
Engineering services	6	8,6
Other services	4	5,7

Source: This Research (2025).

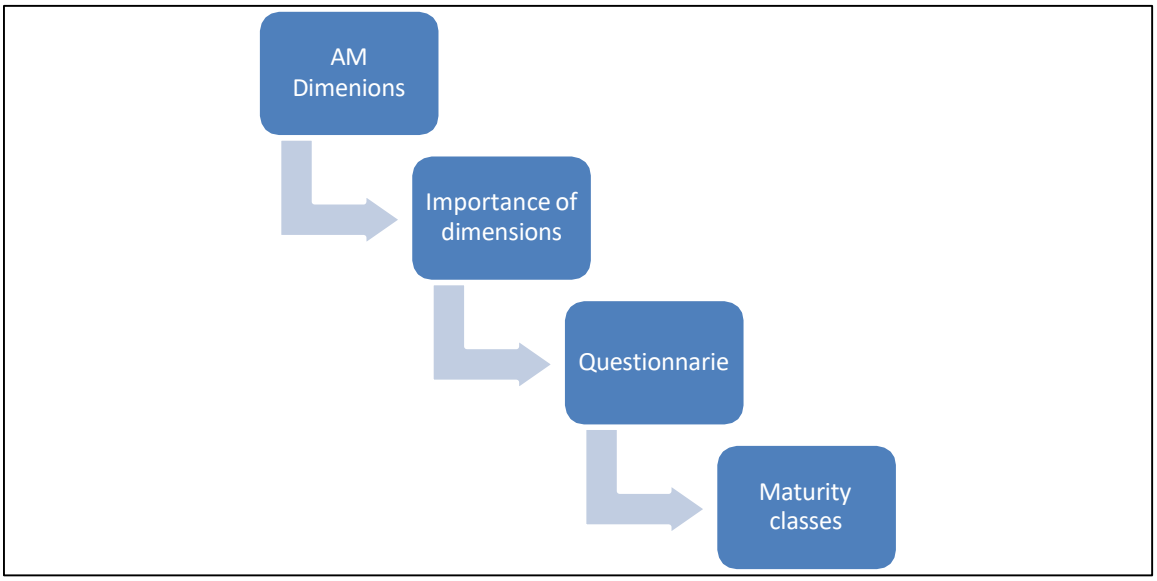
4 MATURITY MODEL AND DECISION SUPPORT SYSTEM

This chapter presents the referential model used to assign maturity classes to organizations. In addition, presents a procedure to apply the reference model, which is based on a DSS.

4.1. Referential Model

The referential model must provide basic elements to guarantee the application and, consequently, the interpretation of the outcomes of the application. The proposed referential model is composed of AM dimensions, the importance of dimensions, questionnaire, and maturity classes (Figure 8), which is proposed by LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b).

Figure 8 – Elements of the Referential model



Source: This Research (2025).

In the MM field, dimensions represent key processes or core dimensions that are composed of a cluster of activities, which are essential to improve the managerial process (PAULK *et al.*, 1993). In this sense, based on the most cited dimensions in the literature review and enterprise reports, ten AM dimensions were chosen to be inserted

in the referential model (LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b). Table 17 describes each of the ten AM dimensions.

Table 17 – AM dimensions of AMAP

Dimension	Definition (GFMAM, 2014)	Main Elements (GFMAM, 2014)
AM Policy	"The principles and mandated requirements derived from and consistent with the organizational / corporate plan, providing a framework for the development and implementation of the asset management strategic plan and the setting of the asset management objectives"	• Guide to develop and implement AM strategies and Objectives. • Should be aligned with stakeholders, policy and constraints Top manager, communication, and regular review to improvement
AM Strategy and Objectives	"The strategic plan for the management of the assets of an organization that will be used to achieve the organizational / corporate objectives."	• The strategic plan (Long term) • Describe current and future service level and AM capabilities • A description of how the AM strategy fits the AM Management System
AM Planning	"The activities to develop the Asset Management plans that specify the detailed activities and resources, responsibilities and timescales and risks for the achievement of the asset management objectives."	• The cost associated, Outcomes expected, and resources necessary • Include the activities necessary to deliver regulatory, industry, and technical standards • How the plan will be approved, monitored, reviewed, and updated.
Data and Information Management	"The data and information held within an organization's asset information systems and the processes for the management and governance of that data and information."	• Quality and accuracy of that data management (owners, consumers, validation, and expected life of data) • Is it fit for purpose and consistent with requirements and standards?
Asset inf. Systems	"The asset information systems an organization has in place to support the asset management activities and decision-making processes in accordance with the Asset Information Strategy"	• Provision, operation, and maintenance of all AIS necessary to deliver the Artificial Intelligence requirements defined in the AM strategy.
AM Leadership	"The leadership of an organization required to promote a whole life asset management approach to deliver the organizational and Asset Management objectives of the organization."	• Influence people toward a vision and a purpose (deliver the AM strategy and objectives of the organization) • Define their responsibilities and accountabilities
Competence mgt	"The processes used by an organization 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"	• Managing the ability of individuals in asset management roles to perform their work activities as well as expected • strategies to cover individual and organizational competencies and best practice frameworks • Periodic assessment of individuals against a competence framework; Identification of training needs
Risk assessment and mgt	"The policies and processes for identifying, quantifying and mitigating risk and exploiting opportunities"	• Describe policies and processes for the identification, assessment, analysis, and treatment of risks and opportunities
Asset performance and health monitoring	"The processes and measures used by an organization to assess the performance and health of its assets using performance indicators."	• Define critical measures that link to organizational objectives • Establish monitoring programs for evaluating performance measures and analysis • Establish processes that evaluate if the asset is performing in accordance with ... • Monitor against the prescribed criteria = deviations • Allow prediction of future asset Performance and health
Asset Costing and Valuation	"An organization's processes for defining and capturing 'as built', maintenance and renewal unit costs and the methods used by an organization for the valuation and depreciation of its assets."	• Define the composition of all costs related to an Asset • Refer to accounting or econometrics rules that allow estimate and predict the value of assets over their lifecycle • Decompose i.e., break down the assets of an organization into their stand-alone parts

Source: This Research (2025).

It is fundamental to incorporate the importance of dimensions in the referential model, once that AM dimensions do not have equal importance across the AM industries (AL MARZOOQI; HUSSAIN; AHMAD, 2019; IAM, 2014). However, there is not consensus in how to assign the weight to each dimension in the literature and practice. Therefore, it is used as a relative importance of the AM dimensions the weight proposed by LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b), which uses the frequency of dimension in the AMMM literature.

Once the AM dimensions and main elements are defined, the organization has enough information to perform the AM assessment. In this aspect, the precise definition is crucial for assessment, as this leads to a common understanding of the constructs employed. Based on these definitions, three questions were selected from the AM literature to represent each construct. The questionnaire is structured in Appendix B.

So, each process should be assessed based on objective evidence, considering the scope and objective of the assessment (ISO, 2008; MACKERRON; MASSON; MCGLYNN, 2003). For this, all questions have 5 levels of evidence, with the first level 0 representing the absence of evidence for the question, and the maximum score 4 representing that the organization has completely attended.

Finally, as mentioned, the AMMM literature does not have a consensus around the AM classes, existing different maturity classes for AMMMs (GFMAM, 2021). In order to support the establishment of the maturity class, it takes into account the evolutionary steps that enable the continuous improvement of the process (PAULK *et al.*, 1993). Considering this context, six classes based on IAM, (2024) were adopted.

Table 18 summarizes the AM maturity classes and their definitions.

Table 18 – Definition of AM classes

Class	Definition
Not applied	"The organization is not aware of the importance of the Asset Management activities"
Aware	"The organization is aware of the importance of the Asset Management Activities and has started to apply this knowledge"
Developing	"The organization is developing its Asset Management Activities and embedding them"

Competence	"The organization's Asset Management Activities are developed, embedded and are becoming effective"
Optimising	"The organization's Asset Management Activities are fully effective and are being integrated throughout the business"
Excellent	"The organization's Asset Management Activities are fully integrated and are being continuously improved to deliver optimal whole life value"

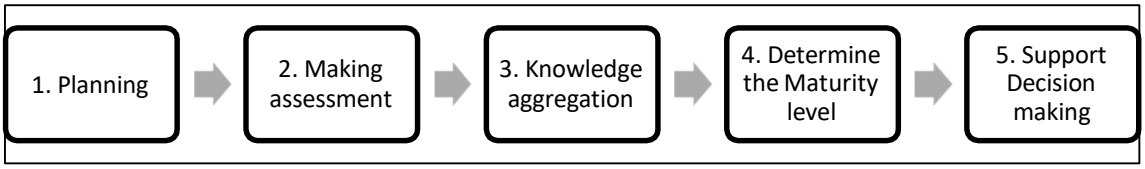
Source: adapted from (IAM, 2014; OFWAT, 2017).

At this stage, the reference model does not specify the operationalization of its application. For instance, it does not describe how to aggregate the assessment results or how to classify them into AM maturity levels. Most of AMMM provided in literature did not develop or use a procedure for support AMMM application. Then, these aspects, including the procedures for result aggregation and classification, will be addressed in the next section.

4.2. AMAP – assessment procedure implemented in DSS

AMAP integrates the procedure assessment into a DSS, that is, the steps provided in the self-assessment procedure (Figure 9) are incorporated in the DSS. AMAP is available freely at www.cdsid.or.br/amap in English and Portuguese (BR) languages. The DSS was developed in the Delphi 2010 environment, using the Object Pascal programming language. Furthermore, it is designed for integration with a graphics library (TeeChart®) and MySQL database.

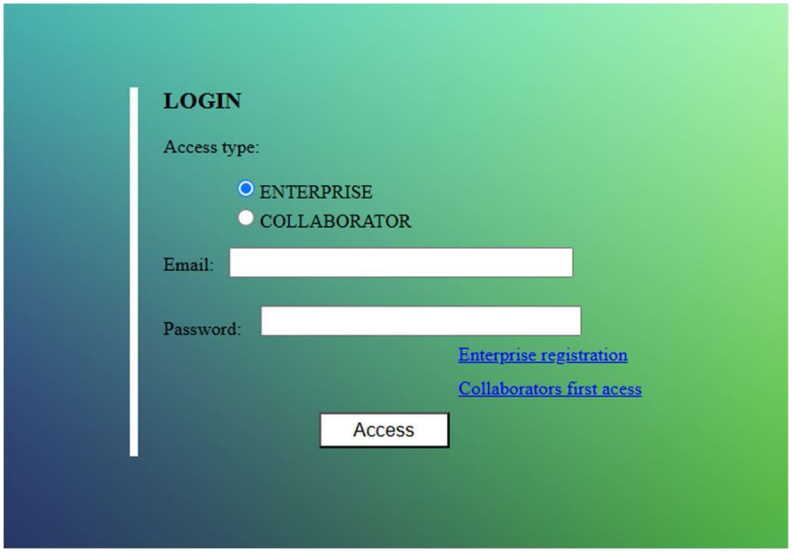
Figure 9 – Self-assessment procedure



Source: adapted from (LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b)

Figure demonstrates the initial screen of AMAP, where users can access the features of DSS, including the use and registration processes.

Figure 10 - Initial screen of AMAP



Source: This Research (2025).

4.2.1. Planning

The assessment maturity is a complex activity, which demands activities to organize, control, and manage the assessment in order to achieve effective results with the maturity assessment. Hence, the initial activity in AM maturity assessment is the planning stage, which should include a set of elements that improve the success. A relevant element that must be established and communicated is the goals of the AM assessment, which improve motivation and commitment (CHERRAFI *et al.*, 2021; SAMUELSSON; NILSSON, 2002).

Furthermore, in planning, the organization must develop activities that guarantee the commitment of top management and employees involved in the assessment of maturity (HILLMAN, 1994). Consequently, top management exerts influence in the assessment, which should encourage participation and build an open, constructive, and safe process (ISO, 2008).

Additionally, planning involves other elements (CHERRAFI *et al.*, 2021; GFMAM, 2021; IAM, 2024; PORTER, 2012):

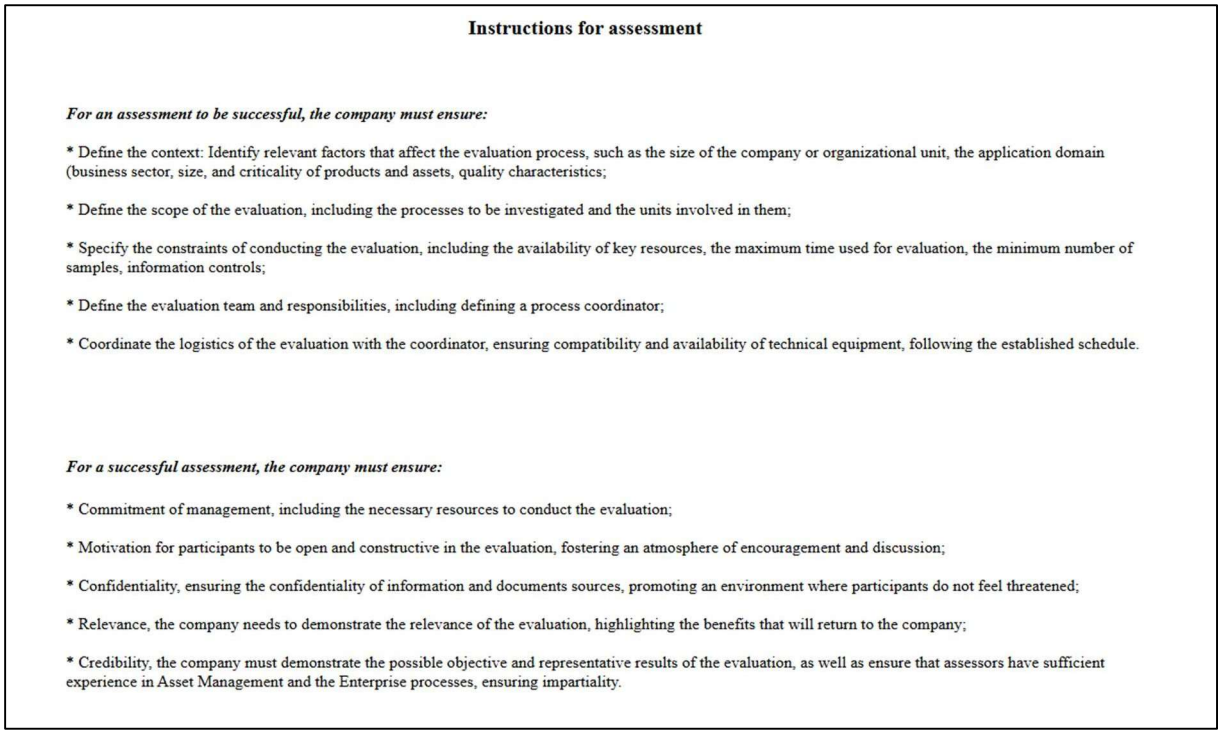
- Determining the organizational context:
  - the size of the organizational unit in assessment.
  - the criticality of the asset system.
  - the key characteristics of products and services of a unit.
  - the resources needed for assessment and the process of assessment.
- Determining the scope and constraints of assessment.
- Determining the team assessment.

- Providing key documentation such as the organizational and AM objectives.

During the subscribing process, the leader of the assessment or the organization has access to these instructions, presented in Figure 11. These instructions are guidelines that are described below.

The organization needs to choose a reference model (HILLMAN, 1994; MACKERRON; MASSON; MCGLYNN, 2003; SAMUELSSON; NILSSON, 2002), in this case, the AMMM should be selected or developed by the organization. The proposed AMMM is a potential model to use in asset-intensive industries. Having organized the contextual information and chosen AMMM, the assessment team should be built, which should ensure an appropriate mix of education, training, and experience in the AM processes, including the determination of roles and responsibilities of the members of the assessment team (ISO, 2008).

Figure 11 –Screen of instructions for the maturity assessment



Instructions for assessment

For an assessment to be successful, the company must ensure:

* Define the context: Identify relevant factors that affect the evaluation process, such as the size of the company or organizational unit, the application domain (business sector, size, and criticality of products and assets, quality characteristics;

* Define the scope of the evaluation, including the processes to be investigated and the units involved in them;

* Specify the constraints of conducting the evaluation, including the availability of key resources, the maximum time used for evaluation, the minimum number of samples, information controls;

* Define the evaluation team and responsibilities, including defining a process coordinator;

* Coordinate the logistics of the evaluation with the coordinator, ensuring compatibility and availability of technical equipment, following the established schedule.

For a successful assessment, the company must ensure:

* Commitment of management, including the necessary resources to conduct the evaluation;

* Motivation for participants to be open and constructive in the evaluation, fostering an atmosphere of encouragement and discussion;

* Confidentiality, ensuring the confidentiality of information and documents sources, promoting an environment where participants do not feel threatened;

* Relevance, the company needs to demonstrate the relevance of the evaluation, highlighting the benefits that will return to the company;

* Credibility, the company must demonstrate the possible objective and representative results of the evaluation, as well as ensure that assessors have sufficient experience in Asset Management and the Enterprise processes, ensuring impartiality.

Source: This Research (2025).

Table 19 summarizes the main requirements for the members of this team. If there is a lack of knowledge, an AM education program can be developed (HILLMAN, 1994; SAMUELSSON; NILSSON, 2002).

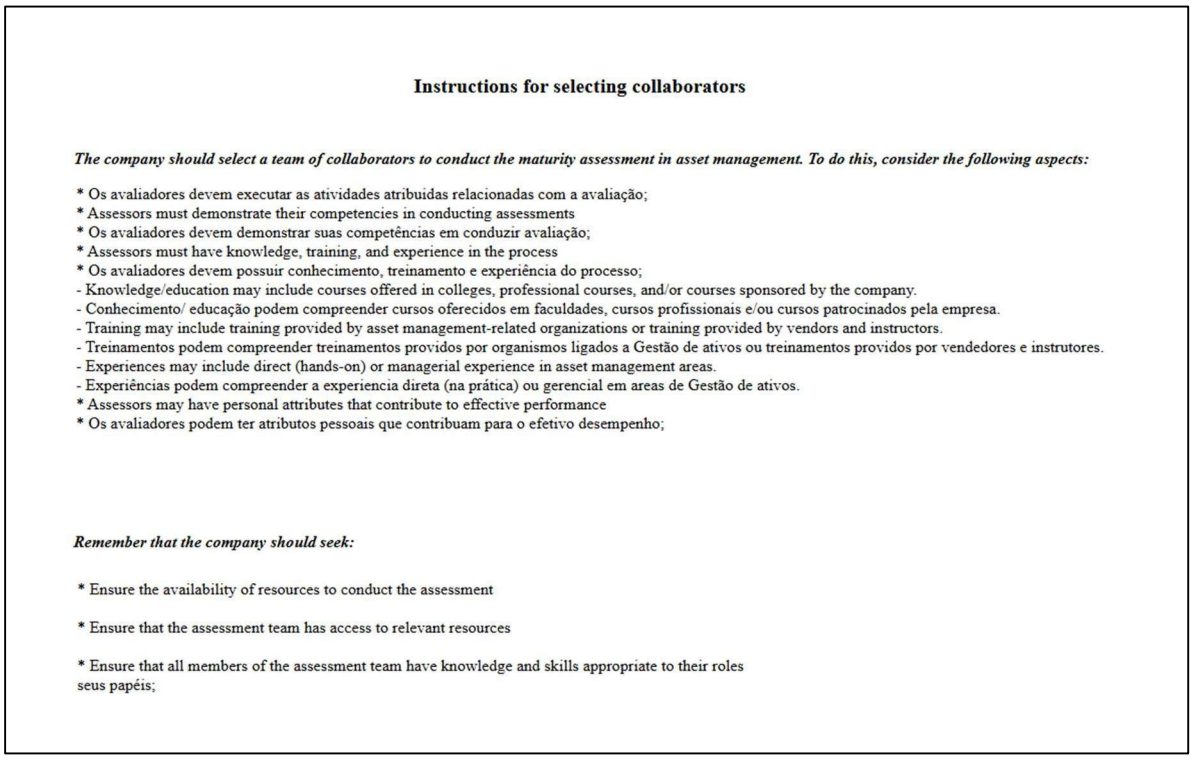
Table 19 – Knowledge, skills, and personal behavior required of staff involved in the maturity assessment

Knowledge (ISO, 2016)	**Skills (ISO, 2016)**	**Personal behavior /Attributes (ISO, 2016)**
business management practices	Note-taking and report-writing Skills	Ethical
		Open-minded
		Diplomatic
Knowledge of audit principles, practices, and techniques	Presentation skills	Collaborator
		Diplomatic
		Observer
Knowledge of specific management system standards/normative documents	Language skills appropriate to all levels within the client organization	Perceptive
		Versatile
		Tenacious
Knowledge of client products, processes, and organization	Interviewing skills	Decisive
		Self-confident
		Professional
		Morally courageous
Knowledge of client products, processes, and organization		Organized

Source: adapted from ISO, (2016)

Importantly, this team should be formed by a vertical and horizontal workforce (AL MARZOOQI; HUSSAIN; AHMAD, 2019; GERSONIUS *et al.*, 2020; IAM, 2024). The ISO (2016a) suggests several categories of methods to support the selection of components for the assessment team, including critical analysis of registers, interviews, tests, and observations, as well as to develop a procedure for determining and maintaining competencies. In order to assist the organization in this aspect, AMAP provides structured instructions to build the assessment team (Figure 12). In addition, the literature does not determine the size of team assessment. Here, at least three members are adopted due the requirements of aggregation process.

Figure 12 - Instructions to compose the assessment team



Instructions for selecting collaborators

The company should select a team of collaborators to conduct the maturity assessment in asset management. To do this, consider the following aspects:

* Os avaliadores devem executar as atividades atribuidas relacionadas com a avaliação;
* Assessors must demonstrate their competencies in conducting assessments
* Os avaliadores devem demonstrar suas competências em conduzir avaliação;
* Assessors must have knowledge, training, and experience in the process
* Os avaliadores devem possuir conhecimento, treinamento e experiência do processo;
- Knowledge/education may include courses offered in colleges, professional courses, and/or courses sponsored by the company.
- Conhecimento/ educação podem compreender cursos oferecidos em faculdades, cursos profissionais e/ou cursos patrocinados pela empresa.
- Training may include training provided by asset management-related organizations or training provided by vendors and instructors.
- Treinamentos podem compreender treinamentos providos por organismos ligados a Gestão de ativos ou treinamentos providos por vendedores e instrutores.
- Experiences may include direct (hands-on) or managerial experience in asset management areas.
- Experiências podem compreender a experiencia direta (na prática) ou gerencial em areas de Gestão de ativos.
* Assessors may have personal attributes that contribute to effective performance
* Os avaliadores podem ter atributos pessoais que contribuam para o efetivo desempenho;

Remember that the company should seek:

* Ensure the availability of resources to conduct the assessment

* Ensure that the assessment team has access to relevant resources

* Ensure that all members of the assessment team have knowledge and skills appropriate to their roles
seus papéis;

Source: This Research (2025).

To sum up, AHMED; YANG; DALE, (2003) cite questions that help in the planning process:

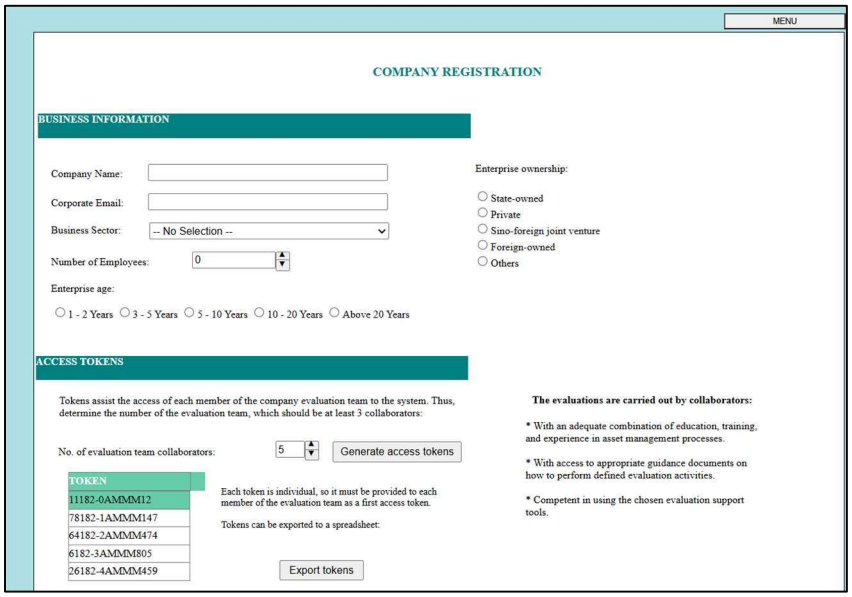
- Is it appropriate for the company not to involve third-party assessors?
- Does the company have an internal expert to act as an assessor?
- Is it more beneficial to employ an external assessor(s)?
- Does the company consistently have enough information to facilitate the self-assessment process?
- Does the company have qualitative and quantitative data to support the assessment procedures?
- Does the company have the right teams to be involved in the process?
- Do these teams, selected in the assessment process, require further training?

The answers to these questions guide the application and the check on the first step of the procedure.

Considering that the organization has followed these guidelines, the planning step is finished with the fulfillment of subscribing information and the generation of individual tokens

for the assessment team. Figure 13 shows the screen where the business information is filled and the access tokens are generated.

Figure 13 – Screen of registration



Source: This Research (2025).

4.2.2. Making assessment

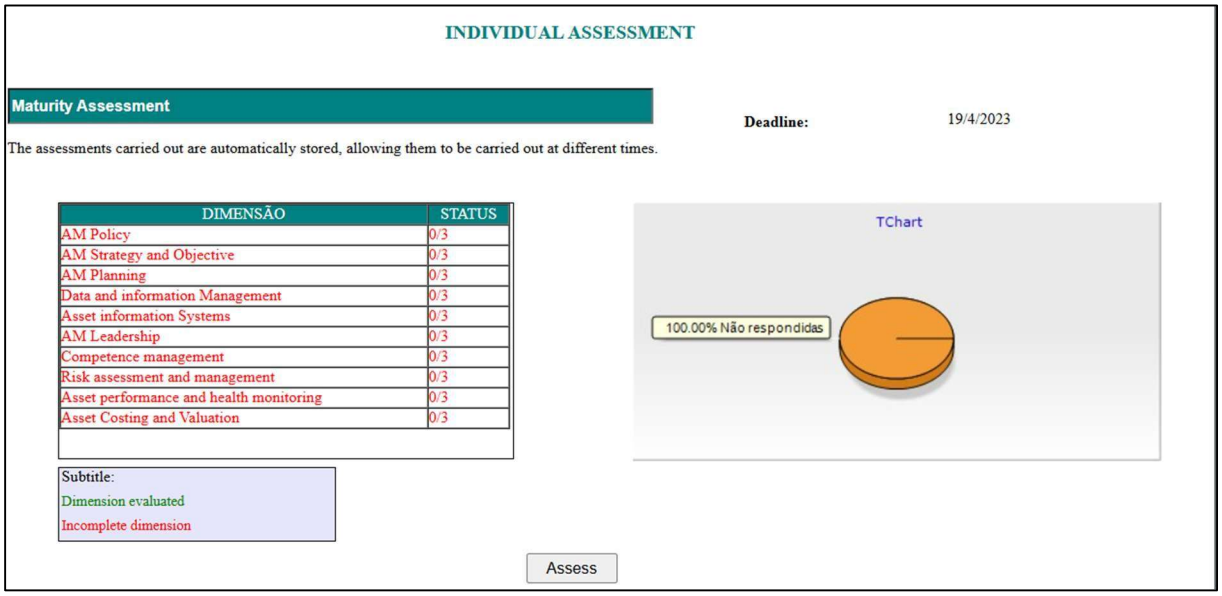
In this step, the organization guides the assessment, which includes providing the manner to collect evidence of maturity (Hillman, 1994), the general guidelines for effective maturity assessment (Cherrafi et al., 2021; ISO, 2004) and the availability of resources and tools, such as questionnaire and DSS used (ISO, 2004; PORTER, 2012). Illustrating this, whether the assessment is based on DSS, the organization needs to assist the staff with computers and enough time to make the assessment.

In order to guarantee the success of the assessment, the organization needs to maintain the confidentiality of the individual assessments, promoting an environment free from threats to confidentiality (GFMAM, 2021; ISO, 2004). Moreover, potential conflicts of interest should be managed carefully (GFMAM, 2021). In this sense, the organization must make available individual tokens for each member of the assessment time, which are generated in the subscribing process, which enables the creation of individual access to the AMAP (Figure 14). Figure 14 presents the screen of individual registration that provides the login credentials.

Figure 14 – Screen of user registration

Source: This Research (2025).

Figure 15 – Screen of individual assessment status

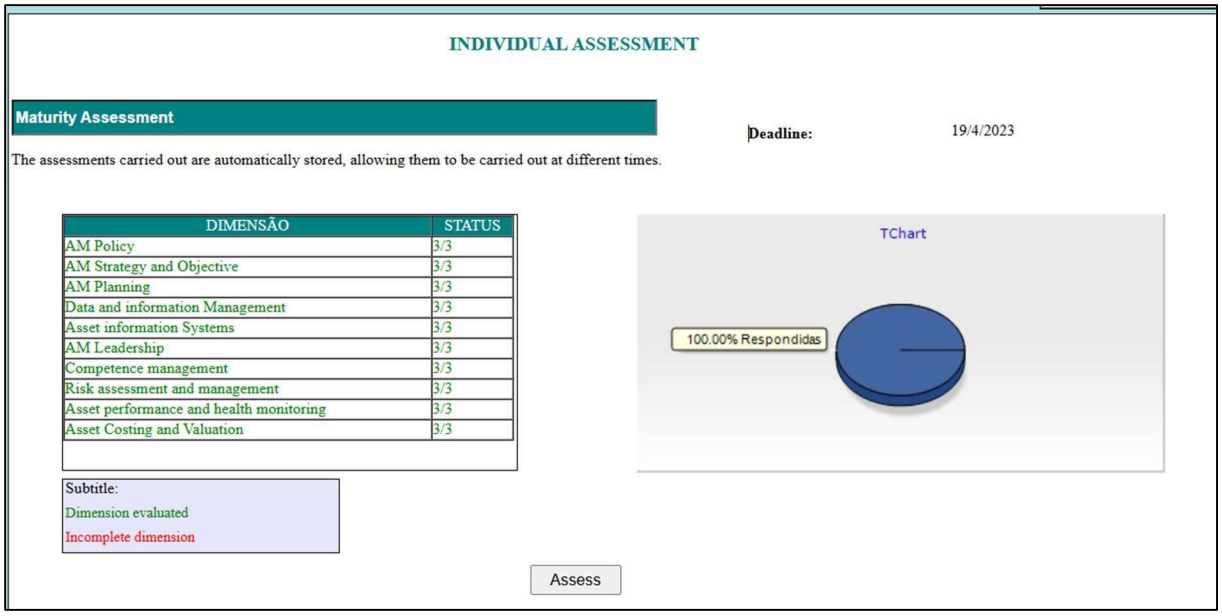


Source: This Research (2025).

Upon AMAP login, the user sees the assessment monitoring screen (Figure 15). In this screen, it is possible to monitor the advancements in the assessment, identifying the number of questions assessed (column labeled status in the table) in each AM dimension, the percentage of questions assessed (in the graphic), and the deadline. While not all the questions of an AM dimension are assessed, the label stays red.

As the user progresses with the assessment, AMAP updates the monitoring screen in real time (Figure 16). The status of dimensions changes, as well as if the user completes the three questions, the color of the dimensions' labels changes to green.

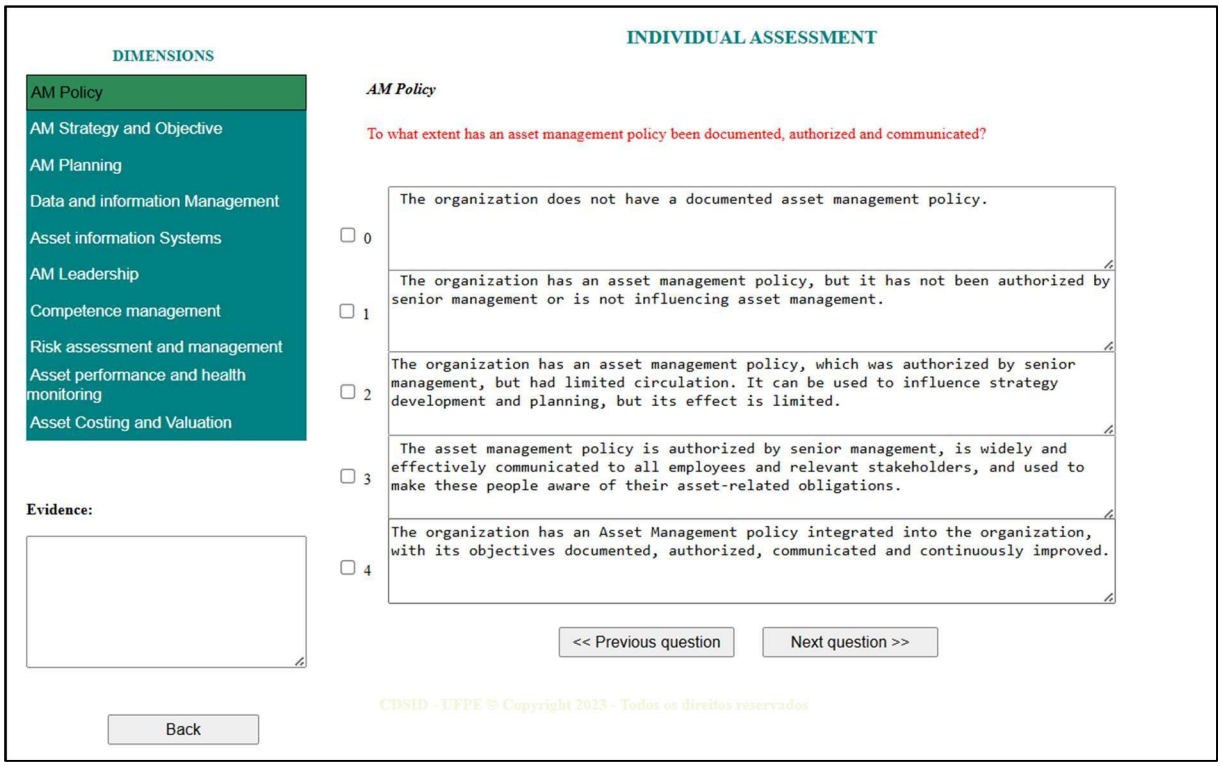
Figure 16 – Progress of individual assessment



Source: This Research (2025).

As mentioned, the maturity assessment is composed of thirty questions based on five levels that describe evidence of AM process capability at each level, which enables the assessment team to evaluate the AM maturity objectively, avoiding subjectivity. In this sense, Figure 17 presents the screen of the individual assessment that displays maturity questions, the description of evidence for each level, and the menu with AM dimensions. If the members want to share evidence for their answers, they can insert it in the evidence field.

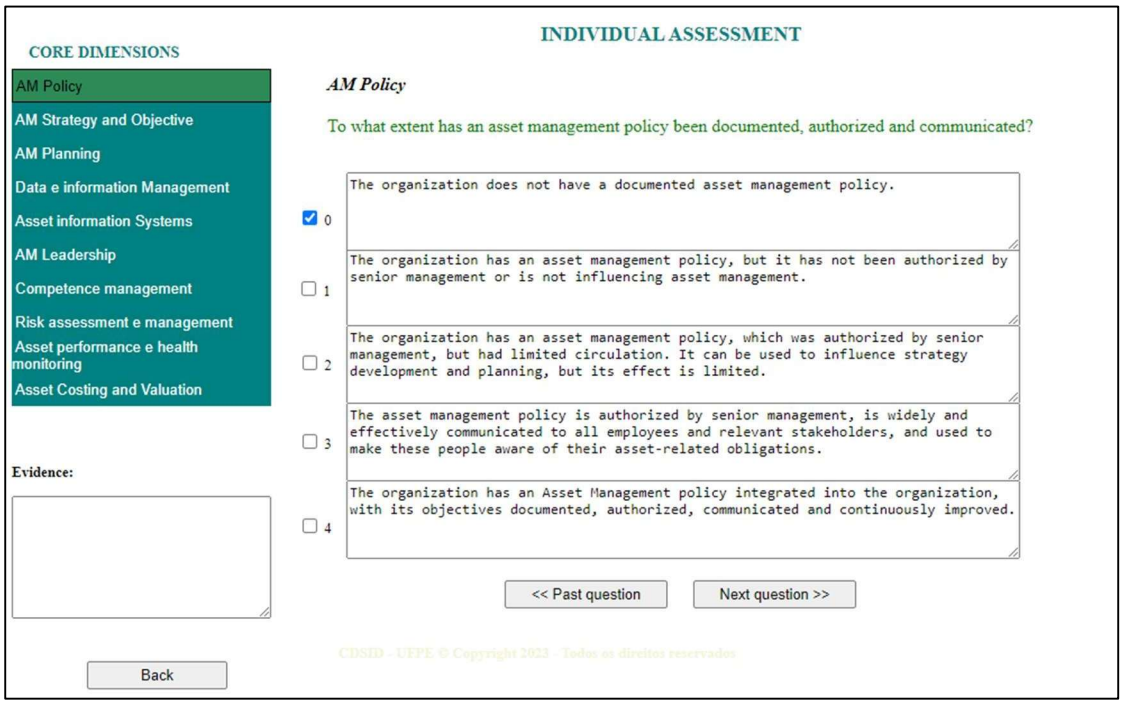
Figure 17 - Screen of assessment questionnaire



Source: This Research (2025).

The members of the assessment team can perform the maturity assessment at their convenience, without the need to complete the assessment in a single session or interaction with the assessment team. This is relevant due to the differences among the staff that compose the assessment team, which is a requirement of the maturity assessment (GERSONIUS *et al.*, 2020; IAM, 2024), the need for available documentation (GFMAM, 2021), and request guidance from the leader of the AM assessment (GFMAM, 2021; IAM, 2014; PORTER, 2012). So, AMAP stores the advancements of the individual assessment, changing the question label color to green when it was answered (Figure 18).

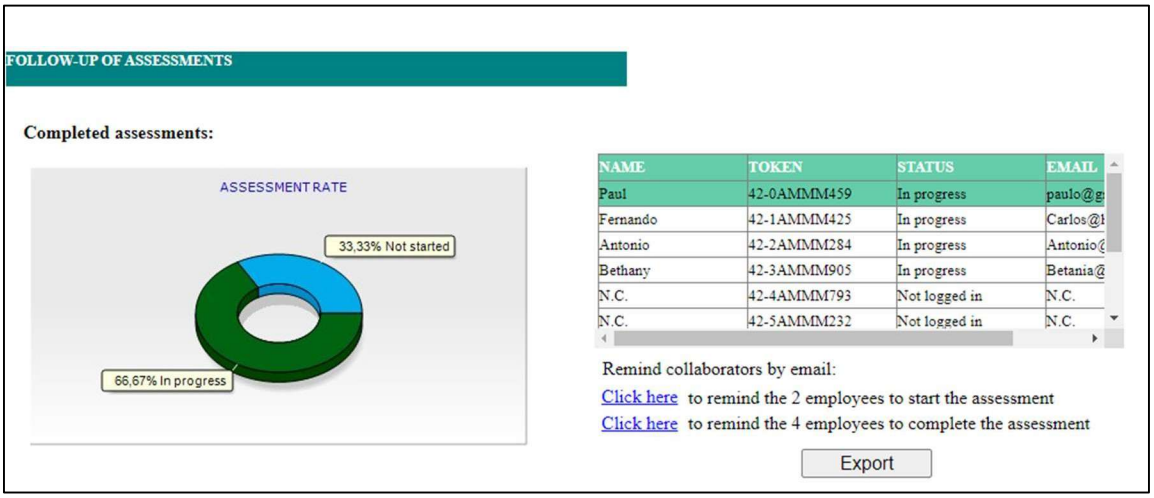
Figure 18 - Progress of the assessment questionnaire



Source: This Research (2025).

From another perspective, it is relevant to monitor and take corrective action to fit the schedule and resources during the assessment (ISO, 2004), e.g., creating reminders and notices to remember to complete the assessment. Especially, the need to have a facilitator or assessor for methodological and commitment support can be reviewed (SAMUELSSON; NILSSON, 2002). Considering this, Figure 19 presents a dashboard to monitor the status of the assessment by the assessment team, which enables control and monitoring of the maturity assessment.

Figure 19 – Screen of the monitoring of the assessment



Source: This Research (2025).

4.2.3. Knowledge aggregation

In the decision-making field, it is widely acknowledged that aggregating information from a group can leverage the accuracy of a decision compared with a solo decision (KAMEDA; TOYOKAWA; TINDALE, 2022; LAAN; MADIROLAS; DE POLAVIEJA, 2017), that is, the process for capturing a group opinion has the advantage that it leads to better results than an individual prediction about a system (BUDESCU; CHEN, 2015). This phenomenon is called the wisdom of crowds or collective intelligence, which requires an aggregating process.

The aggregation process can be realized using different approaches. For example, the average is a common method, which can be inadequate in assessment with high variation (CHENG, 2004; LAAN; MADIROLAS; DE POLAVIEJA, 2017). As an example of this challenge, the presence of outliers frequently leads to bias in the assessments. Another approach is to apply statistical analyses, which have demanded overcoming the challenges related to collecting data. In addition, voting approaches and hybrid methodologies can be used.

Considering these approaches, prompting the search for alternative ways to achieve collective wisdom (BUDESCU; CHEN, 2015; LAAN; MADIROLAS; DE POLAVIEJA, 2017). Albeit the assessment maturity uses evidence, its nature is composed of subjectivity and imprecision during the process (AHMED; YANG; DALE, 2003), which can be overcome using Fuzzy Set Theory (ALTAN KOYUNCU; AYDEMIR; BAŞARIR, 2021; BERTASSINI *et al.*, 2022; SOARES *et al.*, 2021). So, fuzzy methods can also be used to aggregate experts' opinions in the AM context.

Considering the grading process, in which the individual assesses a system using the predefined range of numbers, and also the vagueness and subjectivity in human judgment, CHENG, (2004) presents a method to generate fuzzy numbers to aggregate experts' opinions, which required at least three assessments. Based on this method, LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b) propose a knowledge aggregation to capture the wisdom of the assessment team, which is present in the following. This approach allows convergence to a more precise score in the collective assessment.

As mentioned above, the team members complete assessments of AM-related questions that evaluate the process capability. In this sense, for each question the *n* employees provide a rating $g\ (\ g_1, \ldots, g_n)$, using a five-point scale. In order to use the aggregation method proposed by CHENG, (2004), the ratings for a given question *y* need to be different at least one evaluation,

that is, $g_1 \neq g_n$ for at least one pair of employees' assessments. Then, if all ratings for a particular question are identical, no aggregation method is required.

This method aims to localize the center for each question using the corresponding $g_i$assessments. So, the ratings more proximate to the center are considered to have greater importance, with the aim of mitigating the bias introduced by outliers. For this, calculate the distance matrix $D = [d_{ij}]_{nxn}$for each y question, where $d_{ij} = |g_1 - g_n|,\ i = 1, \dots, n, j = 1, \dots, n$. Specifically, d_{ij} calculate the distance between the ratings assigned by evaluators.

Afterwards, the average of relative distances ($\bar{d}_i$) is calculated for each evaluator i (equation 1), which enables the closeness to the center of all scores to be evaluated. Precisely, $\bar{d}_i$ demonstrates the level of distance of rating assigned by evaluator *i*, which the higher it is, the lower its contribution to the collective score of question *y*. Then, it is proposed a weight to each evaluator *i* for each question *y*, considering the contribution for collective score.

$$\bar{d}_i = \frac{1}{(n-1)} \sum_{j=1}^{n} d_{ij} \quad (1)$$

For this, it is calculated a pair-wise comparison matrix $P = [p_{ij}]_{nxn}$ (Equation 2), considering the proportion of the average distance. The lower the average distance, the higher the weight assigned to the evaluator *i.*

$$p_{ij} = \frac{\bar{d}_j}{\bar{d}_i} \quad (2)$$

Then, using equation 3 is obtained the weight for n evaluators.

$$k_j = \frac{1}{\sum_{i=1}^{n} p_{ij}}, j = 1, \dots, n. \quad (3)$$

Therefore, to achieve the score that represents the employees' assessments in each question is defined as $m = \sum_{i=1}^{n} k_i g_i$, which is the weighing between the ratings and weights of evaluator *i*.

Similarly, to obtain the aggregation of each dimension s, we incorporate the average of the set of questions of each dimension (equation 4).

$$A_s = \frac{1}{Q_s} \sum_{i=1}^{Dm} \sum_{y=1}^{Qs} k_{iy} g_{iy}, i = 1, \dots, D_m \ and \ y = 1, \dots, Q_s \quad (4)$$

Where A_s is the average of AM dimension s, D_m is the number of decision-makers, Q_s is the number of questions of AM dimension s. It is worth noting that A_s represents the process capability, which varies from zero to four (five levels of evidence provided to each question).

Finally, it is important to mention that the number of employees involved in the assessment should be chosen by enterprises. As mentioned in planning step, the more reviewers there are, the more accurate the evaluation in describe the reality. Therefore, this aggregation model enables the value nearer of collective evidence.

4.2.4. Determine the maturity level

Assigning an AM maturity class is a complex activity in maturity models, which demands tools and guidelines to support it (AHMED; YANG; DALE, 2003). As the maturity classes are defined, the issues emerge in assigning a class to each enterprise that is adequate to the current level of AM practices, setting this problem as a classification problem.

To support classification of alternatives in defined groups, in this thesis the maturity classes in AM, Multi-criteria decision aiding (MCDA) can be used (ZOPOUNIDIS; DOUMPOS, 2002). In addition, the studies involving MCDA sorting problems have increased, having many models for application (AMOR *et al.*, 2023). However, MCDA approaches require the elicitation of parameters, such as weights, profiles of classes, and boundaries, demanding requesting knowledge and information of the decision maker around the MCDA sorting problem, which improves the complexity of the assessment process (GRECO; MATARAZZO; SLOWINSKI, 2002).

On the other hand, rough set methodology can be used for solving sorting problems, supporting decision analyses (AMOR *et al.*, 2023; GRECO; MATARAZZO; SLOWINSKI, 2002; ZOPOUNIDIS; DOUMPOS, 2002) , which generate decision rules based on a set of decision examples, that represent the preference model (GRECO; MATARAZZO; SLOWINSKI, 2002). Highlight that the application of the rough set theory faces challenges in modeling system that requires computational models and methods (SKOWRON; DUTTA, 2018), as well, the current models need to be further studied (ZHANG; XIE; WANG, 2016). Therefore, adding rough set and MCDA methodologies may increase the complexity of the procedure, hindering the applicability of the procedure and the accuracy of outcomes.

In order to avoid the complexity in classification, a linear approach has been applied, which guarantees an ordinal scale that supports the evolutionary approach of the maturity model

(PAULK *et al.*, 1993). As mentioned in the knowledge aggregation session, the questions of the dimension are aggregated to build the capability of dimensions, which reflect the range of questions (0 to 4).

In addition, as also mentioned, the relevance of dimensions should be incorporated in the maturity assessment. So, equation 5 uses the maximum frequency of dimension *s* as a proxy for its relevance, which were obtained by the literature review (19 AMMMs).

$$w_s = \frac{f_s}{Max\ f_s}\ , \qquad s = 1\ to\ 10\ AM\ dimension \qquad (5)$$

Where w_s is the weight of dimension s, which is obtained by the maximum frequency f_s of AM dimension *s*.

So, considering the relevance of AM dimensions found in literature, the capability and weight of dimensions are aggregated to form a single indicator (Equation 6):

$$Ml = \frac{1}{\sum_{s=1}^{Di} w_s} \sum_{s=1}^{Di} A_s . w_s\ ,\ s = 1, \dots, D_i\ and\ Ml \in [0,4] \quad (6)$$

Where Ml is the maturity level, D_i $is\ the\ number\ of\ dimensions$.

Therefore, considering the range 0 to 4 of Ml was established the boundaries of the AM classes (Table 20).

Table 20 – Boundaries of AM Classes

AM Classe	Boundaries
Not applied	$Ml = 0$
Aware	$0 < Ml < 1$
Developing	$1 \leq Ml < 2$
Competent	$2 \leq Ml < 3$
Optimising	$3 \leq Ml < 4$
Excellent	$Ml = 4$

Source: This Research (2025).

To conclude this step, the organization needs to examine the assessment results, including the supporting evidence provided by employees (RODRIGUEZ-GARCIA; WHITE, 2005). For example, ISO, (2004) cites the comparison of the previous assessments, seeks consistency between connected processes, and organizes a session to review the results of the assessment as instruments for review.

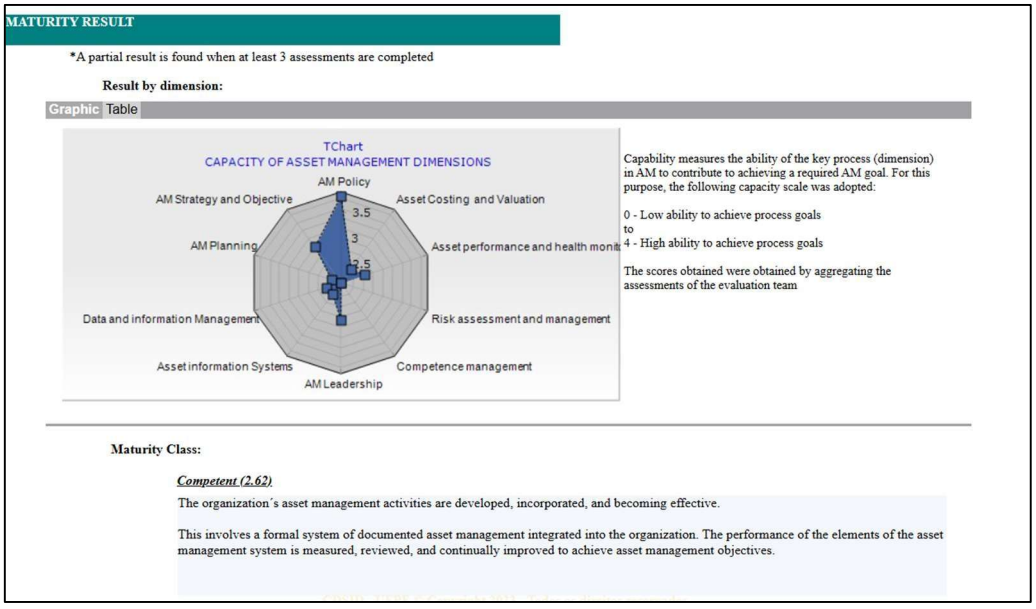
More specifically, about the session methodology, the assessment team produces discussions about the findings and reviews them. At the end of the step, the organization will have a documented report of assessment that covers the outcomes of assessment, including a graphic visualization to illustrate data objectively (CHERRAFI *et al.*, 2021; MACKERRON; MASSON; MCGLYNN, 2003).

4.2.5. Support decision making

The aims of applying a maturity model are to supply the decision-making process and identify the value delivered by AM processes, which allow an improvement path. Therefore, the self-assessment achieves these goals when the outcomes of assessment have been incorporated in the decision-making process, knowledge and learning of the organization, and business planning (RODRIGUEZ-GARCIA; WHITE, 2005; SAMUELSSON; NILSSON, 2002). Therefore, it is fundamental to display the result of the assessment for stakeholders.

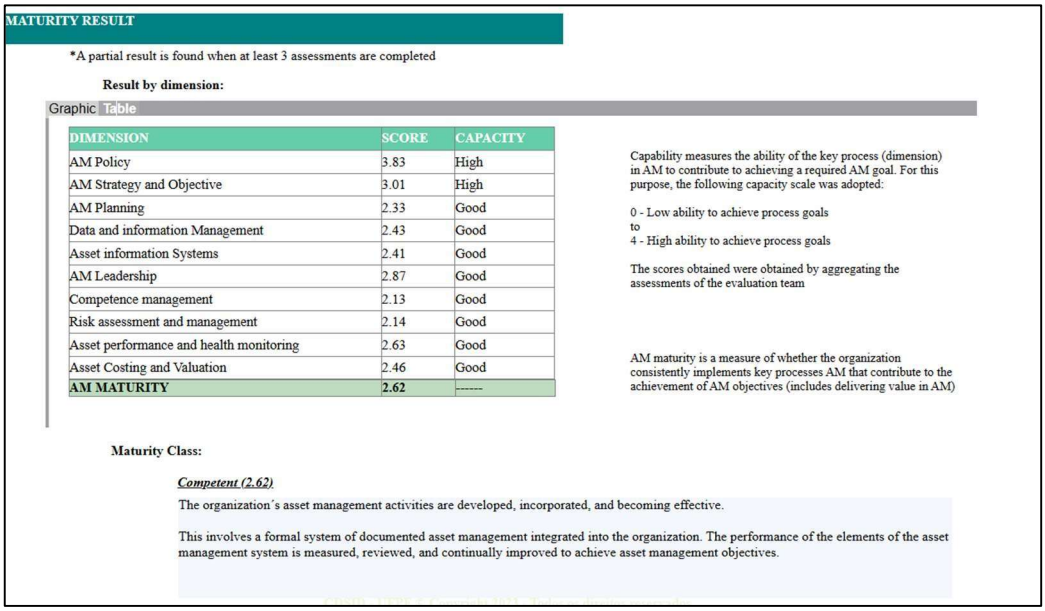
In order to support the decision-making process, AMAP provides graphical and tabular visualizations of the AM maturity results, which are presented in Figures 20 and 21. The results are made available when at least three evaluators complete the assessments. The results are the capability of the AM processes, the maturity level, and the maturity classes.

Figure 20 – Graphical result



Source: This Research (2025).

Figure 21 – Tabular result



MATURITY RESULT

*A partial result is found when at least 3 assessments are completed

Result by dimension:

Graphic Table

DIMENSION	SCORE	CAPACITY
AM Policy	3.83	High
AM Strategy and Objective	3.01	High
AM Planning	2.33	Good
Data and information Management	2.43	Good
Asset information Systems	2.41	Good
AM Leadership	2.87	Good
Competence management	2.13	Good
Risk assessment and management	2.14	Good
Asset performance and health monitoring	2.63	Good
Asset Costing and Valuation	2.46	Good
AM MATURITY	**2.62**	------

Capability measures the ability of the key process (dimension) in AM to contribute to achieving a required AM goal. For this purpose, the following capacity scale was adopted:

0 - Low ability to achieve process goals
to
4 - High ability to achieve process goals

The scores obtained were obtained by aggregating the assessments of the evaluation team

AM maturity is a measure of whether the organization consistently implements key processes AM that contribute to the achievement of AM objectives (includes delivering value in AM)

Maturity Class:

Competent (2.62)

The organization´s asset management activities are developed, incorporated, and becoming effective.

This involves a formal system of documented asset management integrated into the organization. The performance of the elements of the asset management system is measured, reviewed, and continually improved to achieve asset management objectives.

Source: This Research (2025).

4.3. Discussion

4.3.1. Validation of AM Classes

Table 21 – Results of AMAP application

Enterprise	Maturity Level	Maturity class
E1	1.41	Developing
E2	2.62	Competent
E3	1.62	Developing
E4	1.83	Developing
E5	1.75	Developing
E6	1,81	Developing
E7	2.37	Competent
E8	1.7	Developing
E9	0.62	Aware
E10	0.12	Aware
E11	0.64	Aware
E12	1.91	Developing
E13	2.23	Competent
E14	3.13	Optimising
E15	2.93	Competent
E16	2.73	Competent
E17	1.48	Developing

E18	2.84	Competent
E19	3.31	Optimising
E20	1.87	Developing

Source: This Research (2025).

AMAP assigned maturity classes to each enterprise (Table 21) in accordance with the reference and procedure model proposed in this thesis. In order to evaluate the precision of AMAP providing AM classes adjusted to current AM practices, evidence, and feedback were collected with the leader of the team assessment as an approach to validate the construct (Table 22). It is worth noting that enterprises did the assessment by themselves, without interactions with researchers, which is a manner to evaluate artefacts in design science research (BAGNI *et al.*, 2024).

No one enterprise was assigned in no applied and excellent classes, so the analysis was performed for the other ones. Considering the feedback, most companies agreed with the class assigned to them, except E3 and E7, which partially agreed. The reasons and implications for these disagreements are explained in the managerial implications section.

Table 22 – Evidence of AM classes

Class	Evidence
Aware	The company does not have any asset management system at the moment; The importance of an asset management system is understood. There is great interest on the part of top management in implementing an asset management system. E11
Developing	The asset information system is an Excel spreadsheet that, according to the asset manager, is sufficient to meet the basic control, location, and reporting needs to supply the accounting sector. […]. There is no other information to make decisions or to plan whether or not to purchase new assets. E17. The result was as expected. As we have isolated asset management practices, there is a large investment in monitoring the health and performance of assets. E20.
Competence	In terms of asset management, we employ modern resource and operations management practices. This includes advanced mining technologies, efficient logistics for transporting minerals, and investments in research and development to increase efficiency and reduce the environmental impact of our operations. The company also has a considerable focus on sustainability and corporate social responsibility, and thus seeks to minimize its environmental impact and to contribute to the development of the communities where it operates. E18.
Optimising	There is an asset management policy with an asset management plan with objectives, duties, and responsibilities, where the procedures are contained in software with all other corporate standards. New asset investments are

	widely discussed with stakeholders. […] The corporate asset management department has asset lifecycle management for all assets. […] There is an efficiency information system that monitors the asset performance with detailed performance information, preventive and corrective maintenance costs, etc. […]. Competency management is invested in autonomous maintenance and training of operational, tactical, and strategic teams in the organization to improve knowledge and the delivery of objectives. E14.

Source: adapted from (LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b)

Considering the aware class, AMAP assigned three enterprises in this class, which although they recognize the benefits and outcomes of AM activities, few initiatives have been developed or drawn up by them. In this sense, these enterprises can have developed some AM processes due to a reaction to the organizational environment. Consequently, these processes do not deliver value from assets intensively.

Although these enterprises agree with the class, it was no evidence (see E11) that they are starting to AM program as the definition of the Aware class proposes. As can be seen in the Figure, these enterprises do not have reasonable capabilities in most AM dimensions, and the great scores are a standalone effort that does not contribute to delivering value using AM.

Table 23 – AM maturity of enterprises assigned to the aware class

Dimension	**E9**	**E10**	**E11**
AM Policy	1,27	0,07	0,13
AM Strategy and Objectives	0,93	0	0,33
AM Planning	0,67	0,07	0,67
Data & Information Management	0,33	0,33	0,6
Asset Information Systems	0,8	0	0,67
AM Leadership	1	0,33	0,87
Competence Management	0,73	0,07	1
Risk Assessment and Management	0,33	0,07	0,27
Assets Performance and Health Monitoring	0,33	0,07	0,93
Asset Costing and Valuation	0,67	0,2	0,93
AM Maturity	**0,68**	**0,12**	**0,64**

Source: This Research (2025).

To solve this inconsistency would be more adequate to classify them in No applied, and consequently, the threshold between awareness and no applied classes be reviewed. However, this solution was not applied to reformulate the class for the following reason: the barriers to

starting AM practices, such as bureaucracy, lack of AM plans, and constraints of human and financial resources (BEITELMAL *et al.*, 2017; SANDU; VARGANOVA; SAMII, 2023) . Therefore, as it was not conclusive, it did not change either the model or the procedure.

Most of the enterprises were classified as belonging to the developing class, indicating that they have incorporated AM initiatives across the organization in an elementary and fragmented manner. Then, the AM implementations tend to be driven by specific needs rather than applied comprehensively throughout the organization. Although these enterprises recognize the importance of AM, its integration into business remains inadequate. This evidence can be seen in E17 and E20, whose AM actions are limited to the silos of AM recognized by them. In addition, they do not have any initiative to develop an AM system.

On the other hand, in a competent class, an initial AM system must be documented and implemented, which must be aligned with organizational objectives. Six companies were classified in the competent class, demonstrating that they have developed AM practices and capabilities, as well as having used tools that support AM dimensions. As can be seen in E18, there is evidence that AM practices are used to achieve organizational objectives connected with sustainability.

Finally, two companies attain the Optimizing class, thereby demonstrating effective and integrated AM practices into the business, e.g., E20 has AM policy and many AM practices in its routine. However, E14 describes some challenges that need to be addressed to achieve the best delivery value by assets. For example, structured data is not available to employees, and there is no governance data that establishes the data access across the business. Consequently, some information is lost during the solicitation of data.

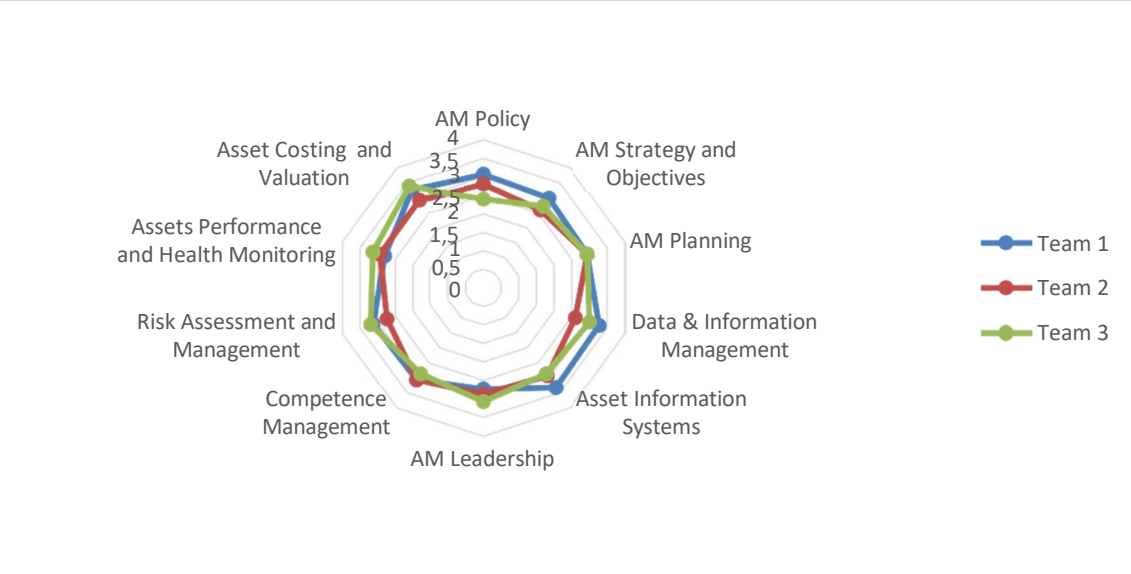
4.3.2. Results

AMAP proved effective in assigning AM maturity levels to asset-intensive organizations across different production systems. In line with this. E18 carried out a self-assessment using three separate teams and achieved comparable outcomes in AM dimensions (Figure 23). Therefore, this result reinforces the AMAP's capacity for replication and broad applicability.

As introduced, E3 and E7 agree partially on their AM results. E7 achieves good results in AM dimensions, being assigned to the competent class. However, the leader of the assessment team demonstrated an expectation for better results in the strategic AM dimensions.

Seeking to understand the reasons for this, as part of the assessment procedure, the leader provides that the members of the assessment team probably had difficulty understanding questions related to strategy.

Figure 22 – Results of AMAP applications on E18



Source: adapted from LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, (2025b)

Taking into account this, the difficulty of understanding strategic aspects may suggest the absence of organizational capabilities related to strategy, which include the communication and documentation of AM policy. This inference is collaborating with previous studies that demonstrate the absence of a strategic view in the AM context (BROWN *et al.*, 2014; GAVRIKOVA; VOLKOVA; BURDA, 2020; SANDU; VARGANOVA; SAMII, 2023). Moreover, the presence of disagreement does not undermine the AMAP's effectiveness but emphasizes the interactive nature of the self-assessment (RODRIGUEZ-GARCIA; WHITE, 2005).

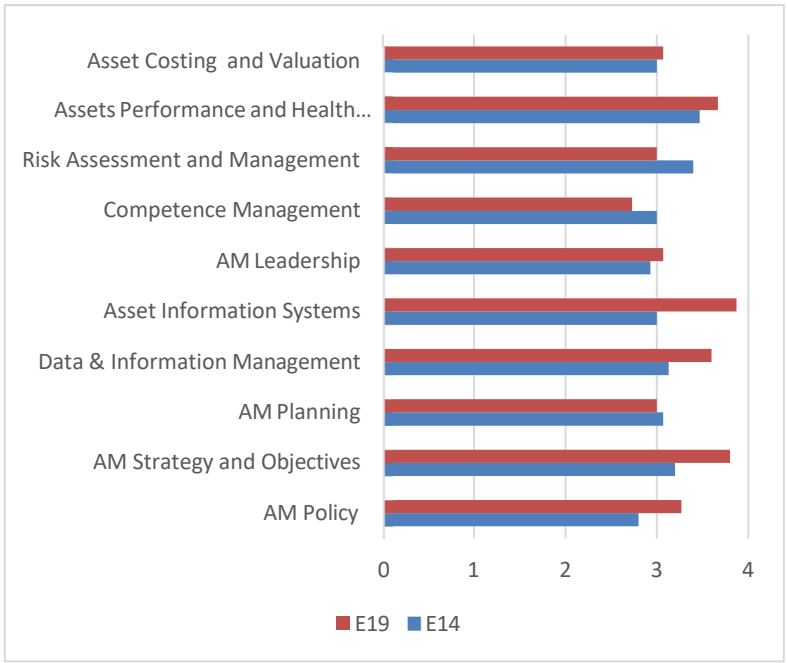
E3 expected a higher AM maturity. By analyzing Figure 23, it is possible to stand out the better result in operational capabilities compared with the strategic capabilities. This is aligned with (LAUE *et al.*, 2014) that highlights that in the AM context there is a focus on the operational level, such as asset performance, while negligence the strategic level. In this context, strategic AM processes consider stakeholders' requirements and organizational objectives to drive AM programs, objectives, priorities, and activities(BARTON; JONES; GILBERT, 2002; IAM, 2024).

Figure 23 – Results of AMAP applications on E3

Source: This Research (2025).

Consequently, the low capacity in strategic dimensions may limit the development of AM dimensions, contributing to the AM maturity achieved by E3. In addition, the low performance in the AM policy is critical, which provides organizational guidelines to develop AM plans and objectives(GFMAM, 2024). Therefore, E3 does not have evidence to establish formal processes for the development and communication of AM Policy across the business.

Figure 24 – Results of AMAP applications on E19 and E14



Source: This Research (2025).

Companies E19 and E14 achieved the best results in the sample (Figure 24), being classified in the optimizing category, which demonstrates the integration of AM practices into their business routines. Company E19 obtained the highest capabilities in most dimensions, except for AM Policy, Competence Management, and Asset Costing and Valuation. Although E19 was not the top performer in these dimensions, its capabilities remain high. Analyzing the context of its operation, it was identified that the assets are located offshore.

Assets in the ocean are operating in an environment exposed to high risk, which in the failure of the asset system may cause economic, human, and environmental harm, making physical assets critical to operation. In line with this, there are government regulations to promote effective operation offshore. For example, BRASIL, (2022) establishes the regulatory note 17 that comprises requirements for safe, healthy, and living conditions at work on board oil safety platforms operating in Brazilian waters, which must be followed in AM Policy. Moreover, the possibility of damage generates pressures to implement risk management (RAJESH, 2019).

E14 has provided practical evidence for the class assigned by it, which is an interesting mention AM Policy, Data & Information Management, and Asset information system. The organization describes and develops documentation that contains its AM policy, which has guided the organization and it is aligned with integrated management system policy. In order to support this integration, E14 has an AM system that integrates AM across all units. As self-assessment produces reflective approach, that is, as the organization applies the assessment and obtains results, this information must be confirmed with organizational practice (ISO, 2004).

In this reflective approach, given the difficulties some team members face in bringing or identifying evidence in the self-assessment, E14 could diagnose that AM principles, practices, guidelines, tools, and concepts need to have better publicity within the business. Another point for improvement is the establishment of risk assessment approaches that must be integrated into AM policy and guide all company units in mitigation actions and measure risks. It is worth noting that E14 is not in the same context as E19, but risk management has been acknowledged as a driver in AM (GFMAM, 2024; IAM, 2024; KURE; ISLAM, 2019; SAYERS *et al.*, 2021).

Yet, E14 also highlights an interesting challenge regarding asset review competencies (Asset Cost and Valuation and asset performance and health monitoring dimensions). The enterprise reveals that although there are maintenance practices and performance indicators,

few efforts have been carried out to measure and identify the effectiveness of AM practices. That is, the organization has data around assets and AM processes, however it does not have expertise to turn this data into information that enables inference about the effectiveness of AM. This finding collaborates with PARLIKAD, A. et al., (2014) and GAVRIKOVA; VOLKOVA; BURDA, (2020), which stand out that there is a challenge in connected AM practices, asset performance and business performance

Both E14 and E19 have high capability in Asset Performance and Health Monitoring and AM Objectives and Strategies dimensions. Although the range varies among them, it can infer that these dimensions are relevant to optimizing class. In this sense, these enterprises have invested in processes to develop objectives and strategies that will be followed for all AM initiatives. In addition, AM review is a traditional locus of investment in AM context, which is linked with maintenance practices and decision-making in prioritization of investments.

Table 24 – Results of AMAP applications on enterprises assigned to the competent class

DIMENSION	E2	E7	E13	E15	E16	E18
AM Policy	3,83	2,13	1,73	3,49	2,33	**2,8**
AM Strategy and Objectives	3,01	2,47	2,07	3,26	2,6	2,6
AM Planning	2,33	2,33	1,53	2,64	2,53	2,93
Data & Information Management	2,43	2,2	2,4	2,96	2,87	2,6
Asset Information Systems	2,41	2,6	1,93	2,93	2,4	2,93
AM Leadership	2,87	2,33	2,4	2,97	3	2,87
Competence Management	2,13	2,67	2,8	2,87	2,6	3,07
Risk Assessment and Management	2,14	2,2	2,47	2,72	2,87	2,73
Assets Performance and Health Monitoring	2,63	2,33	2,07	2,61	3	2,93
Asset Costing and Valuation	2,46	2,6	3,13	3,09	3	2,93
AM MATURITY	**2,62**	**2,37**	**2,23**	**2,93**	**2,73**	**2,84**

Source: This Research (2025).

Table 24 describes the capabilities of enterprises assigned to the competent class. Before proceeding with the analysis, it is important to highlight that the aim is not to make a comparison among these enterprises, but to bring some implications. Neither the best nor the lowest capacities are the same for enterprises; that is, it is not possible to identify a standard among the enterprises. This point reaffirms that the relevance of AM dimensions, and consequently prioritization, is related to organizational context (AL MARZOOQI; HUSSAIN; AHMAD, 2019; IAM, 2014), so that each enterprise seeks to develop its most important areas.

Most core dimensions of company E2 demonstrate good capacity to achieve the required AM goal. Notably, the AM Policy as well as the AM Strategy and Objectives exhibit high capacity, reflecting a strategic and long-term perspective toward asset management. In addition, the organization has Industry 4.0 technologies, such as digital twins and 3D printing. As mentioned, Industry 4.0 technologies have supported AM initiatives (BIARD; NOUR, 2021; SANDU; SAMII, 2021), which demands the establishment of an AM policy to support the resources, guidelines, and commitment needed to guarantee the implementation of asset-centered technologies.

Conversely, feedback from the team assessment indicated that top management tends to overestimate the actual performance of AM practices and may overlook challenges more readily observed at the operational level. This finding reinforces the importance of constituting an assessment team composed of employees who perform different jobs in hierarchical levels (GERSONIUS *et al.*, 2020). Moreover, the team leader remarked that it would be valuable to reapply the model in the future to evaluate existing gaps and determine whether implemented actions have effectively enhanced maturity.

As mentioned, improving the learning process is fundamental to continuous improvement in MMs fields, which can be supported by the self-assessment process (BITITCI, UMIT S. *et al.*, 2015; MACKERRON; MASSON; MCGLYNN, 2003; RITCHIE; DALE, 2000). In this sense, E15 highlights that using AMAP resulted in the improvement of knowledge about AM, including characteristics and requirements in AM dimensions that the enterprise does not have knowledge. By analyzing the performance in Table 24, E15 is close to achieving a new AM maturity class, the optimization.

Currently, the AM planning and Assets Performance and Health Monitoring competencies are less developed than other AM dimensions. Considering the AM planning, it can be inferred that the organization has challenges in turning AM objectives and strategies in organizational plans into business, consequently, E15 has difficulty allocating resources, detailing activities, defining responsibilities and timescales, and specific risks (GFMAM, 2021). Similarly, Assets Performance and Health Monitoring dimension is relevant due to the growing demand for constant monitoring through new technologies.

E18 demonstrates its strongest performance in the area of competence management. The leader provided some evidence about these AM dimensions. Firstly, E18 has dedicated a department for AM, demonstrating the relevance of AM practices for business. Secondly. The

AM department is composed of a multidisciplinary team, reinforcing the interdisciplinary approach required to promote an effective AM (EL-AKRUTI; DWIGHT; ZHANG, 2013; KOMONEN; KORTELAINEN; RÄIKKÖNEN, 2012). Finally, this department aims to ensure operational efficiency, employee safety, and the sustainability of the corporation, which collaborates with holistic approaches required by AM (AMADI-ECHENDU, 2004; PETCHROMPO; PARLIKAD, 2019).

Each organizational branch has different stakeholders. In this sense, some pressures are more present in some branches, which sometimes enterprises that operate in such sectors face regulatory pressures (LIMA, E. S.; CABRAL SEIXAS COSTA, 2019;SCHÄFER; HIRSCH; NITZL, 2022). For example, in the electrical power context, there are laws and regulations that affect AM, such as ANEEL Normative Resolution No. 907/2020 that provides guidelines for maintenance, indicators, and reliability. In this context, these regulations emphasize key areas of asset management, including maintenance, depreciation, reliability, and service continuity (see Table 25).

Table 25 – Some Brazilian laws related to AM

LAW	SUMMARY	RELATION WITH AM
Law 9.427/1996	ANEEL is responsible for regulating and supervising the generation, transmission, distribution, and commercialization of electrical power.	Requires concessionaires to maintain infrastructure in proper conditions.
Law 10.848/2004	Concessionaires must ensure the quality and continuity of electricity supply.	Demands preventive maintenance and asset reliability.
Law 13.360/2016	Establishes obligations for modernization and maintenance of facilities and equipment in the electricity sector.	Reinforces the duty of updating and caring for assets.
ABNT NBR 16357/2015	Guidelines for asset management in the electricity sector, focusing on planning, maintenance, and risk.	National standard specifically for electricity asset management.

Source: This Research (2025).

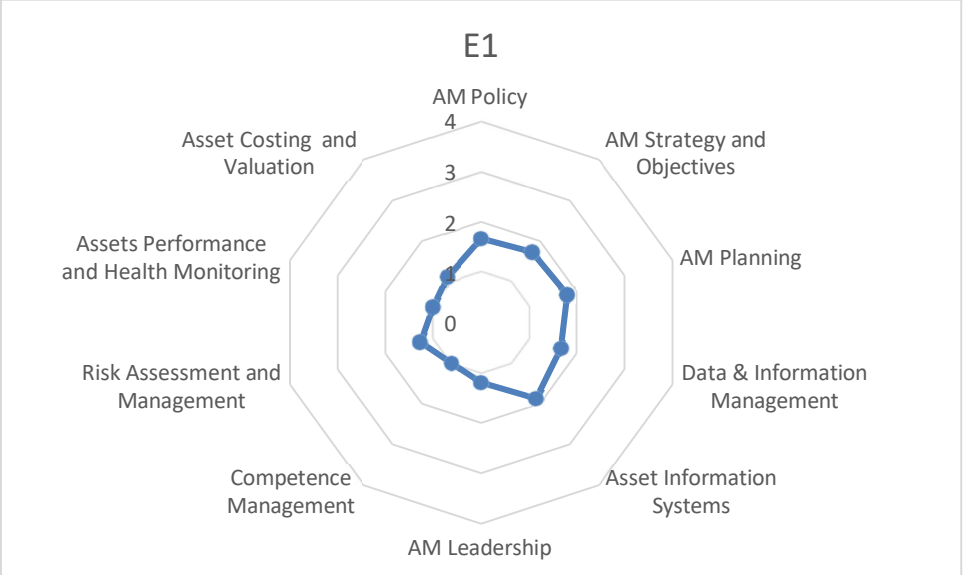
Under these circumstances, E13 stands out that its AM practices are driven by regulatory requirements. The enterprise presents three stages of AM practices:

1. Decentralized AM. In this stage, the organization used local databases and tools intensively, such as spreadsheets. There is no integration of AM into business.
2. Implementation of the AM system. The organization establishes an AM system to integrate AM across the business.

3. Creation of a maintenance sector dedicated to AM practices. As mentioned, there is a need for commitment and guidance of AM implementation. In this sense, an organizational sector can leverage the outcomes of AM initiatives.

E1 was assigned in the developing class, which demonstrated that the organization has introduced some AM practices. As can be seen in Figure 25, the competencies related to Strategic AM and Information management are more developed than other competencies. So, it is possible to identify a lack of asset performance and review, people management, and risk management, which are operational areas of AM. These results are concerning, mainly because E1 has around 2300 assets in its operation. Therefore, it can be inferred that E1 may be losing the maximum return on assets, demonstrating the need to proceed to improve AM practices.

Figure 25 – Results of AMAP applications on E1

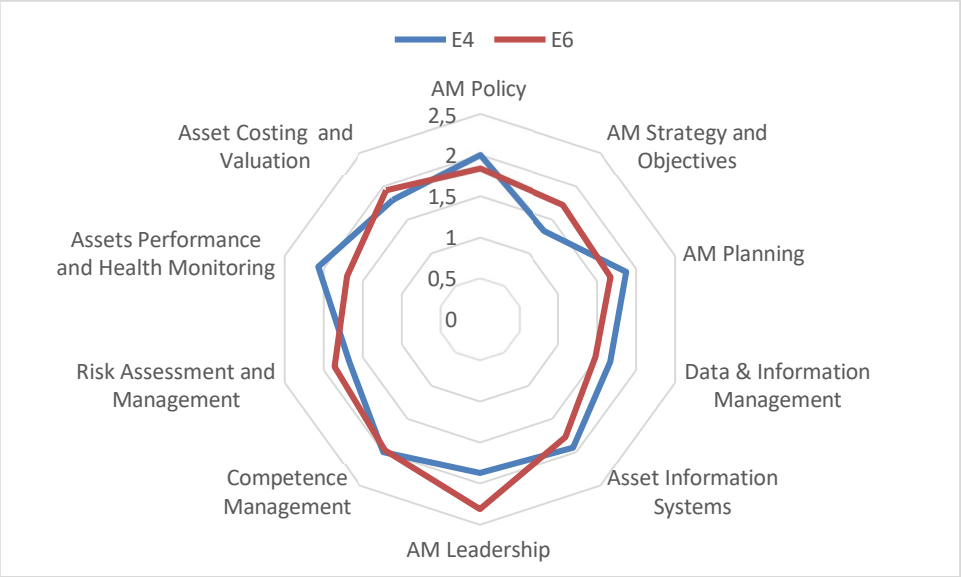


Source: This Research (2025).

By analyzing enterprises classified in developing class, some insights can be pointed out. As can be seen in Figure 26, E4 and E6 achieve similar AM maturity and AM capabilities, with the exception of AM strategies and objectives, AM leadership, and Asset performance and healthy monitoring. It appears that E4 achieves a better understanding of maturity assessment, which can produce roadmaps and guidance using the data and knowledge acquired in self-assessment, as mentioned in the decision-making step.

In this sense, E4 developed some guidance to improve AM. First, although the organization does not mention developing an AM policy, the team suggests the development of AM guidelines that provide a clear vision for the organization in AM, which must include the strategic dimensions. Second, the organization can apply long-term approaches in decision-making processes, as mentioned above the decision in the AM context produces results in the long term. Third, E4 demonstrates interest in developing a procedure or process flow to enable it to apply AM guidelines, which is linked to the demand for tools to support AM (SANDU; VARGANOVA; SAMII, 2023). Finally, the organization needs to establish storage of data and information in a centralized database, which demonstrates the relevance of data stored and available across the organization (GFMAM, 2024; OUERTANI; PARLIKAD; MCFARLANE, 2008).

Figure 26 – Results of AMAP applications on E4 and E6

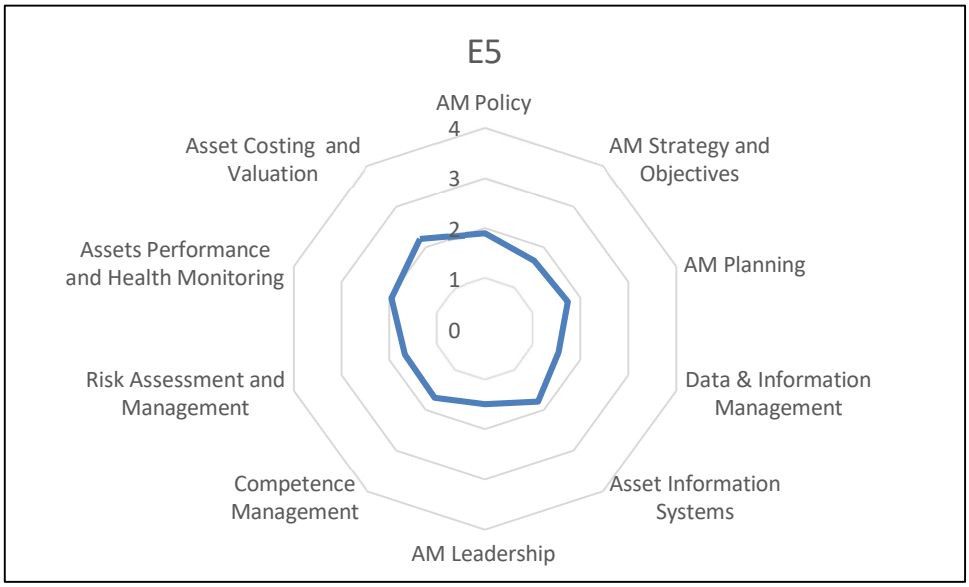


Source: This Research (2025).

Among enterprises assigned to the developing class, E5 achieves better scores in asset costing and valuation. As presented, this dimension aims to evaluate assets and infer about the life cycle of assets. In this context, organizational evidence demonstrates that the operation of assets uses industry 4.0 technologies to capture data, which is used in decision-making. Probably, these technologies have supported this dimension, albeit insufficient to produce

results in other dimensions. In addition, Figure 27 demonstrates that this enterprise has tried developing all AM dimensions, because it has a similar result in AM dimensions, and one the lowest standard deviations among the sample.

Figure 27 - Results of AMAP application on E5



Source: This Research (2025).

Similarly, to occur in the other enterprises, E20 also demonstrated an absence of evidence for AM Policy (Figure 28). Around this low result, the leader team stands out that AM strategic approaches are seen as bureaucratic documentation. This comment can highlight two problems in AM context that must be overcome:

- Inadequate awareness. Unfortunately, asset-intensive organizations lack of awareness of AM as role for implementation of organizational strategies (EL-AKRUTI; DWIGHT; ZHANG, 2013).
- Barries to AM implementation. MALETIČ et al., (2023) find that the increasement of documentation and bureaucratic are relevant barriers to enterprises that need to be overcome.

It is worth noting that this enterprise has developed concrete actions in asset performance and health monitoring, being the better result among developing class. E20 has a system to monitor critical parameters of assets at all times. This system provides dashboards to

demonstrates the health of assets, which will enable decision-making processes such as establishing maintenance policy.

Figure 28 – Results of AMAP application on E20

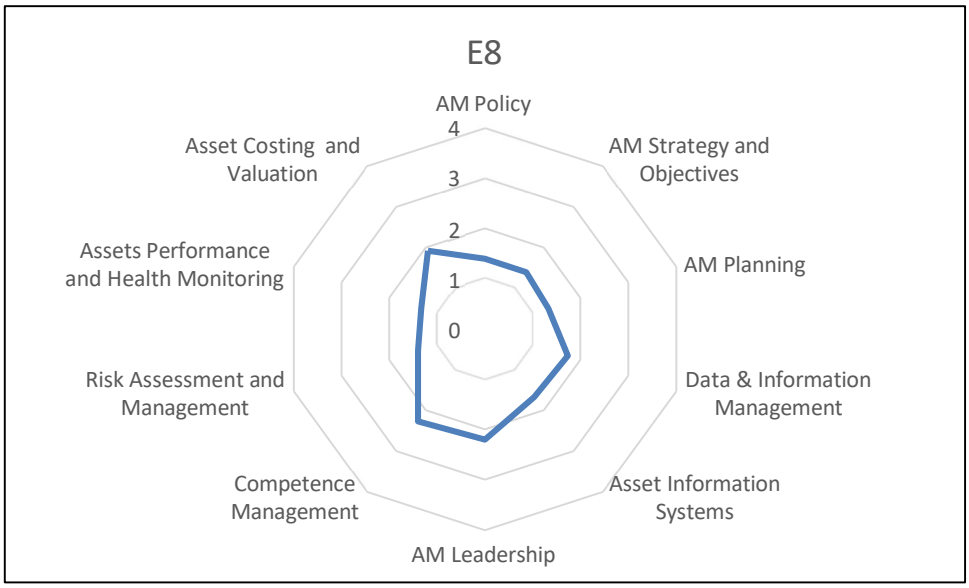
Source: This Research (2025).

Figure 29 presents the AM capabilities assessed by enterprise E8. With this result, some challenges have been mapped by team in some AM dimensions:

- Data and information management: Albeit the assets are storage, there is an absence of information about components, which are relevant to apply some models such as RCM and age replacement. Moreover, there also is obsolete data that reduces the effectiveness of AM practices. In addition, the interoperability problem is present in this enterprise.
- Competence management: the organizations has employees with knowledge in AM, however they have challenges in establishing priorities.
- AM Leadership:

In addition, a positive point is in the AM leadership dimension. The assessment team provides that there is a commitment of top management to support the implementations in AM, including to provide the resources to implement the AM objectives and strategies.

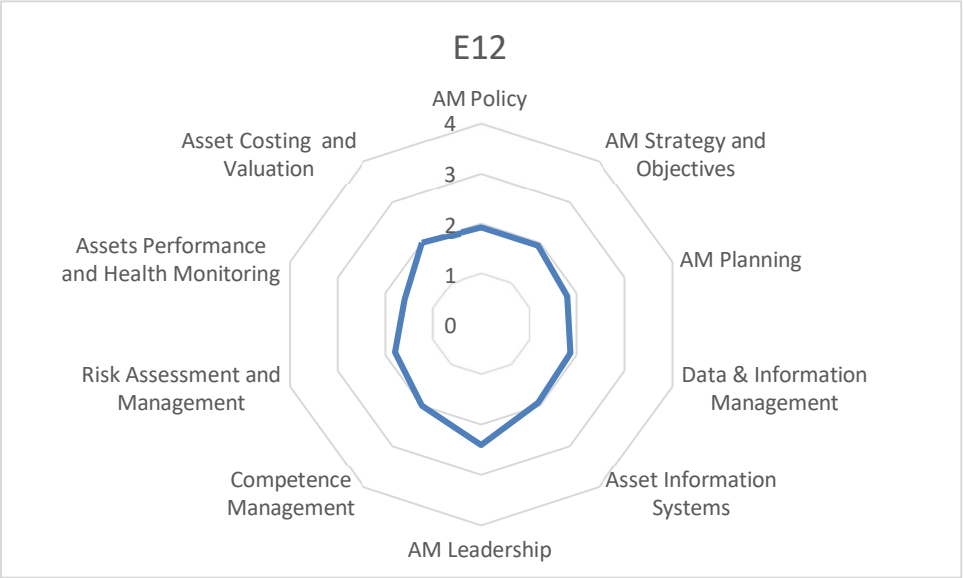
Figure 29 –Results of AMAP application on E8



Source: This Research (2025).

E12 is close to overcoming the developing class, demonstrating full evidence to the developing class in AM dimensions (Figure 30). The organization has reactive AM without adequate monitoring of assets, albeit the organization uses the AM system and has good human processes (AM Leadership and Competence Management dimensions). For example, the enterprise has committees for audit, governance, sustainability, and human resources, which aim to guarantee the effectiveness of organizational strategies and objectives. Thus, it has reasonably applied the AM processes.

Figure 30 – Results of AMAP application on E12



Source: This Research (2025).

Figure 31 illustrates the maturity of E17, which shows that the enterprise has developed AM initiatives, albeit being in reactive modes or more present in some AM dimensions than others. In contrast with all AM dimensions, AM leadership presents a better development in E17, which, albeit being a state-owned company, has evidence to support the development of an effective AM.

Figure 31 –Results of AMAP application on E17

Source: This Research (2025).

By summarizing the developing class, Figure 32 brings an overview of the maturity assessment. It can be noted that AM policy and Asset performance and Health monitoring have different capability levels, which suggests that these dimensions are seen in different ways among the sample. In contrast, there is a similarity in Data and information management and asset information systems, which demonstrates that enterprises in the developing class have seen the benefits of developing processes related to data information. This is aligned with AM literature that sets data information as a driver in AM (FAUZAN; PAMUNGKAS; WIBAWA, 2019; POLENGHI *et al.*, 2022).

Figure 32 –Results of AMAP applications on enterprises assigned to developing class

Source: This Research (2025).

E9-E11 were assigned in the aware class, which achieved the low AM maturity in the sample, as can be seen in Table 26.

E9 works with renewable energy and transmission services, which have demonstrated a few AM initiatives in its operations. This result is worrying since the company has more than fifty photovoltaic plants with many assets. Moreover, the next step of organization is to develop and implement AM policy, being this a relevant base to AM programs (GFMAM, 2024). In addition, the organization has acquired information technology service management, which will be implemented to support asset control and inventory.

Table 26 - Results of AMAP applications on enterprises assigned to aware class

DIMENSION	E9	E10	E11
AM Policy	0,53	0,07	0,13
AM Strategy and Objectives	0,6	0	0,33
AM Planning	0,33	0,07	0,67
Data & Information Management	0,47	0,33	0,6
Asset Information Systems	0,67	0	0,67
AM Leadership	1,13	0,33	0,87
Competence Management	0,27	0,07	1
Risk Assessment and Management	0,8	0,07	0,27
Assets Performance and Health Monitoring	0,6	0,07	0,93
Asset Costing and Valuation	0,93	0,2	0,93
AM MATURITY	**0,62**	**0.12**	**0.64**

Source: This Research (2025).

E10 does not have evidence to implement AM activities in a structured manner. The present activities related to AM are maintenance activities, which are outsourced by the company. On the other hand, E11 describes the relevance and benefits, but in this current stage of AM practices does not have an investment in the AM system. Therefore, these enterprises are yet only expecting to begin AM processes.

These findings indicate that the system effectively facilitates the implementation of the proposed AMMM, thereby assisting in the assessment of AM maturity levels and identifying existing gaps. This enables organizations to accurately determine their maturity profile and confidently develop targeted improvement roadmaps. In addition, the assessment procedure shows to be effective to support the AMMM application, contributing to avoid issues related to aggregating knowledge and conflict management.

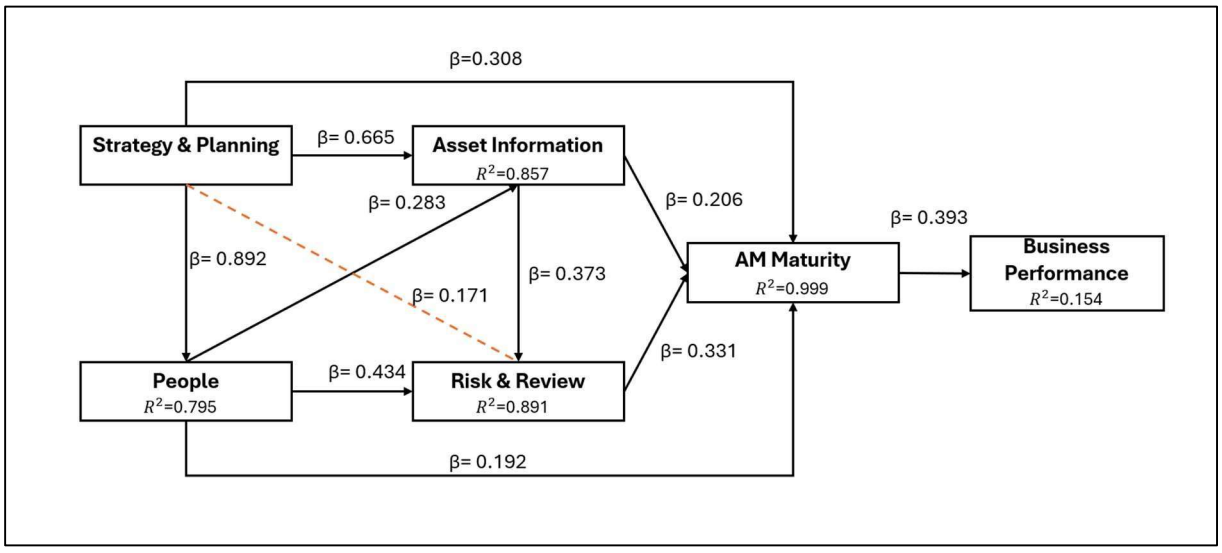
5 RELATIONSHIP BETWEEN AM MATURITY AND BUSINESS PERFORMANCE

5.1. PLS-SEM application

In the PLS-SEM method, the path coefficient (β) is calculated to represent the relationship between constructs, which varies between -1 to +1 (HAIR, JOSEPH F.. *et al.*, 2017). The closer to +1 demonstrates a strong positive relationship. In contrast, β closer to -1 indicates a strong negative relationship. In addition, the R-squared is calculated to complement β results.

In SmartPLS tool, the bootstrapping feature allowed generating 5000 resamples to perform a path coefficient analysis, which is presented in the Figure 33. Considering the main target of this part of the thesis, the relationship between AM Maturity and business performance attains a β of 0.393, which demonstrates a positive association. In addition, the R-squared of 0.154 demostrates that around 15.4% of business performance variation may be explained by AM Maturity.

Figure 33 – PLS-SEM results



Source: This Research (2025).

Moreover, the acceptability and magnitude of R-squared depend on the research topic (BENITEZ *et al.*, 2020; HAIR, JOE F. *et al.*, 2014). In this sense, taking into account that business performance is a multidimensional concept, this low value of R-squared may have

resulted from this. Drawing from prior research, the following evidence regarding the R-squared values of organizational capabilities and business performance can be observed. For example:

- E-business 0.17 (YANG *et al.*, 2010).
- Capital structure 0.394 (CUEVAS-VARGAS; CORTÉS-PALACIOS, 2025).
- Manufacturing flexibility 0.203 (WEI; SONG; WANG, 2017).
- Product and process innovation 0.14 (PRAJOGO, 2016),
- BPM Maturity 0.10 (DIJKMAN; LAMMERS; DE JONG, 2016).

On the other hand, this magnitude probably is related to the nature of business performance that comes from multiple aspects of the organization, including external factors. Therefore, the path coefficient and R-squared demonstrate that establishing continuous improvement in AM maturity influences business performance, providing evidence to support H_1. Table 27 presents the statistics for the relationship between AM Maturity and AM competencies. There is evidence that Risk & Review, Strategy & Planning, Asset Information, and Leadership & People have positive effects on business performance, in that specific order.

Table 27 – Path coefficients linked to AM Maturity

Hypotheses		Path coefficient	Significance	Result
H_2	Strategy & Planning -> AM Maturity	0.308	0.000	Support
H_6	Asset Information -> AM Maturity	0.206	0.000	Support
H_8	Leadership & People -> AM Maturity	0.192	0.000	Support
H_9	Risk & Review -> AM Maturity	0.331	0.000	Support

Source: This Research (2025).

By proceeding to Strategy & Planning competence (Table 28), which has proposed the H_3, H_4, and H_5 hypotheses, it does not find evidence that demonstrates the direct influence of Strategy & Planning competence on Risk & Review. In contrast, an indirect effect was found, which is moderated by Asset Information and Leadership & People.

Table 28 – Path coefficients linked to strategy competence

Hypotheses		Path coefficient	Significance	Result
H_3	Strategy & Planning -> Risk & Review	0.171	0.225	No Support
H_4	Strategy & Planning -> Leadership & People	0.892	0.000	Support
H_5	Strategy & Planning -> Asset Information	0.665	0.000	Support
Indirect				
	Strategy & Planning -> Asset Information -> Risk & Review	0.248		
	Strategy & Planning -> Leadership & People-> Risk & Review	0.387		

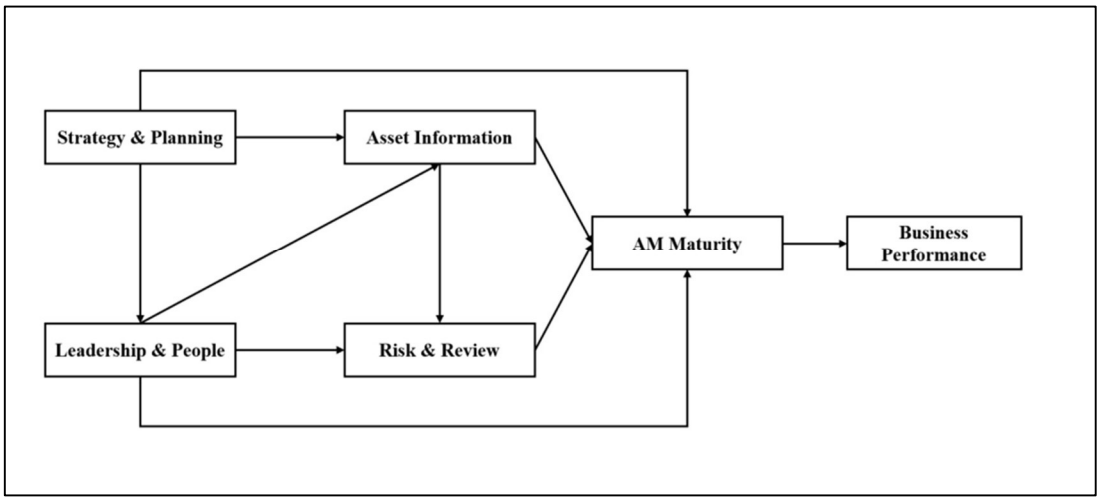
An analysis of the Leadership & People competency reveals that it also contributes to the Asset Information and Risk & Review competencies (Table 29). This finding supports the H_7 and H_{11} hypotheses, which illustrate the relationship between Leadership & People capabilities and the enhancement of Asset Information capabilities.

Table 29 – Path coefficients linked to Leadership & People competence and the control variables

Hypotheses		Path coefficient	Significance	Result
H_7	Leadership & People -> Asset Information	0.283	0.034	Support
H_{11}	Leadership & People -> Risk & Review	0.434	0.001	Support
Control variables				
Company size		0.094		
Age of company		0.052		
Ownership		-1.032		

Source: This Research (2025).

Figure 34 –conceptual model revised



Source: This Research (2025).

Moreover, the effects of the control variables, company size, age of the company, and ownership, are statistically insignificant (Table 29). Therefore, the conceptual model was revised (Figure 34).

5.2. Discussions

These results advance the AM literature, providing empirical evidence of the relationship between AM Maturity and business performance. In this sense, some progress has been made in contrast with previous studies.

Firstly, this thesis establishes a maturity level (score) that translates the degree of AM practices in an organization, and links it to assess its effects on business performance. The AM literature providing evidence relies on AM dimensions and operational performance, which are demonstrated to be relevant to achieving the operational objectives. Then, the findings of this thesis contribute to deepening and exploiting the influence of AM maturity in achieving business performance.

Secondly, as mentioned, previous studies focus on the operational level. In this sense, the strategic perspective has been explored as much, which is aligned with the lack of AM strategic studies (GAVRIKOVA; VOLKOVA; BURDA, 2020; SANDU; VARGANOVA; SAMII, 2023). Therefore, this study proposes a new investigation taking into account the strategic elements of AM, opening ways to new studies involving AM maturity and performance.

Thirdly, the adoption of a maturity model enables the collection of evidence from multiple perspectives, addressing a common limitation in maturity assessment studies where reliance on a single evaluator prevails (TARHAN; TURETKEN; REIJERS, 2016). This approach reinforces multiple evaluations as a critical aspect of the assessment process, which can enhance the overall success of the assessment.

Consequently, these aspects bring advancements for theoretical and methodological perspectives in AM. So, some contributions to managerial practices may be promoted:

- Decision-makers have empirical evidence to demonstrate that investing in programs to implement the AM systems integrated into the full organization has a positive influence on business. Then, this reinforces the potential benefits of AM implementations provided in Section 2.1.
- Given this relevance, managers demand managerial tools to assess AM practices, which stand out AMMMs, such as AMAP. This supports the decision-making based on value and data, which is a challenge in the AM context (PETCHROMPO; PARLIKAD, 2019).
- Reinforcing the establishment of continuous improvement programs in order to assess AM systems and business performance. Consequently, new evidence can be identified in AM operations.

Considering the relationship among AM competencies, it is possible to identify valuable findings. Risk & Review competence, which is composed of asset performance and health monitoring, risk management, and Asset costing and valuation, presents the best contribution in AM Maturity. This finding collaborates with the emphasis given in the AMMMs in this competence (LIMA, GABRIEL HERMINIO DE ANDRADE; COSTA, 2025b; MAHMOOD *et al.*, 2015), as well as demonstrates the level of development in asset-intensive organizations.

On the other hand, Risk & Review competence is influenced by other AM competencies. The path coefficients demonstrated in Figure 33 suggest that the performance of Risk & Review competence is moderated by the capabilities in developing AM leadership and competence management, as well as establishing asset information competencies. These findings are consistent with the risk management and performance management literature:

- Commitment, support of top management, motivation of staff, and leadership are internal factors that provide support to implement risk management approaches (HUDIN; HAMID, 2014).
- People management and information management exert significant effects on the ability of performance management to achieve results (PAVLOV *et al.*, 2017; ROBINSON *et al.*, 2005).
- Data are essential for effective risk management, yet limitations in quality, access, and integration constrain risk management applications (RENAULT; AGUMBA; BALOGUN, 2016). Then, in asset-intensive industries, asset information supports risk activities.
- Information technologies, particularly data integration systems that manage the data access for users and support the decision-making process (LEVINE, 2004; RENAULT; AGUMBA; BALOGUN, 2016), constitute critical enablers in effective risk management.

Strategy & Planning competence exerts direct and indirect influences on Asset Information, Leadership & People, and Risk & Review, which suggests the relevance of developing a strategic AM to leverage these AM competencies. This setting collaborates with the current level of strategic AM, which, during the initial phase, focuses on the operational level, as presented in CHAPTER 2. Therefore, it is relevant to make available tools that support the development of AM policy, AM planning, and AM objectives and strategies, which, as mentioned, sometimes are viewed as bureaucratic, turning into an obstacle to effective AM (BEITELMAL *et al.*, 2017; MALETIČ *et al.*, 2023).

Illustrating the effect of the influence of the organizational strategies, (CROTEAU; BERGERON, 2001) demonstrate that different types of strategies are characterized by distinct technological deployments. In this sense, it is expected that AM strategies demand the development of capabilities related to Asset information, in order to adjust the organization to achieve the objectives.

Similarly, the strategic AM must take into account the AM dimensions related to leadership and people management, once these competencies are fundamental to guide the organization to the objectives established in the strategic development (LIU *et al.*, 2023; MAI; DO; HO NGUYEN, 2022). Specifically in the AM context, these competencies have been

acknowledged as a driver of strategic AM and AM systems (IAM, 2008; LAUE *et al.*, 2014) . Therefore, this result authenticates the relevance to leadership and people emphasized in ISO 55002 (ISO, 2024b).

6 CONCLUSION

AM is a relevant managerial and strategic approach for industries where their operations are based on assets. Organizations that apply AM programs have the potential to achieve better delivery value from assets, although the measurement of contributions faces hard challenges due to the absence of data, the long-term effects of AM decisions, and the complexity of the AM systems. In this context, this thesis proposes a new AMMM, called AMAP, which is composed of a reference model, an assessment procedure, and a DSS.

The relevance and gaps in AM practices that justify the demand to develop AMAP is found in CHAPTER 2. The AM literature demonstrates that AM is composed of AM competencies that describe different processes to achieve an effective AM, which the challenges faced by managers, e.g. data quality, risk management, and people trained, may be solved with AM process well developed. In this context, MMs are tools that assess the capabilities of processes, which are useful for creating roadmaps for improvements on processes.

By analyzing MMs for AM, it was possible to identify that most of them have an absence of the assessment procedures, guidelines for understanding AM classes and their validation, and tools to assist the application. Consequently, the AMMM application has the potential to fail. So, AMAP advances in promoting a new AMMM that is composed of models and DSS that support the correct application, which is demonstrated in CHAPTER 4.

Yet in CHAPTER 4, the validation process is applied, and the results demonstrate the effectiveness of the AMAP assigned AM classes to organizations. So, as validation is essential in the MM field, this thesis offers a new MM that meets the criteria of replicability and generalizability. As a result, AMAP demonstrates confidence in asset-intensive industries, so that dozens of companies have improved their AM capabilities to apply AMAP.

In order to develop AMAP, design science approaches were applied, which comprise interactive processes step-by-step to develop a solution. CHAPTER 3 presents the applications of these approaches, involving the participation of experts and more than sixty employees to provide feedback. A deeper examination of their comments and the supporting evidence is undertaken in CHAPTER 4.

It is worth noting that the assessment procedure is also absent in the MM field. So, this thesis also contributes to this field by demonstrating that this element is fundamental to MM applications, mainly for those that are based on self-assessment. Additionally, the development

of DSS improves the applicability of the referential model, which is rare in the AMMMs found. As result, the enterprises did not present difficulties in the assessment process. Therefore, the assessment procedure demonstrates to be effective in AMMM application.

On the other hand, the AM literature has highlighted that it is essential to describe the relationship between AM maturity and business performance, so as that provide evidence to decision-makers to endorse investment, plans, and strategies focused on AM. In this scope, CHAPTER 2 also establishes a hypothetical model that demonstrates the relationship between AM Maturity, AM competencies, and business performance.

Considering the characteristics of the sample and the aim of this thesis, the PLS-SEM method was adopted. The requirements and application of PLS-SEM are developed in CHAPTER 3. So, summarizing the PLS-SEM results in CHAPTER 5, it is possible to infer that AM Maturity influences business performance. Therefore, this empirical evidence to decision-making processes, which sometimes is based on intuitions instead of data and values as discussed in CHAPTER 2.

In addition, this result also contributes to business process management by demonstrating that the effectiveness level of asset-intensive processes can leverage business performance. Moreover, progress in the AM field by bringing empirical evidence, which reinforces a direct link between AM and performance that is absent in most AM studies, which, for the most part, are based on case studies.

Furthermore, the PLS-SEM method reveals that the AM dimensions related to the strategic perspective work as a driver to influence other AM dimensions. This finding collaborates with the AM literature by legitimizing the relevance to develop AM policy, AM objectives and strategies, and AM planning to guide the implementation of AM initiatives. So, it is possible to infer that developing these competencies is relevant to achieving the effectiveness of AM.

So, this thesis brings theoretical and managerial contributions. Consequently, the impacts of this thesis are identified. Considering the economic perspective, the following impacts are addressed:

- Improvement of delivery value from assets, since the AMAP contributes to the identification of AM dimensions for improvement.
- Supporting asset-intensive organizations in prioritizing actions more adequate to AM maturity and the capabilities of AM dimensions.

- Enabling the organizations to improve the AM system, which influences the business performance.

In addition, social impacts are expected:

- Compliance with stakeholders' requirements. As AM dimensions affect organizational objectives, developing AM dimensions will reflect in quality, flexibility, sustainability, and other requirements.
- Mitigating the risk of failures and accidents.
- Compliance with regulatory laws related to worker security.

Finally, environmental impacts are drawn:

- Improving sustainable performance, because the AM literature demonstrates that AM improves sustainability.
- Compliance with environmental laws that demand the fulfillment of requirements for asset operation and maintenance in order to minimize environmental impacts.

6.1. Limitations and Future works

Despite promising results, it recognizes certain limitations and identifies avenues for future research. Considering AMAP, to aggregate AM dimensions, weights were adopted based on frequency in the AM literature, instead of using the organizational expertise. About this, it is relevant to mention that some challenges emerge when deciding to give opportunities to organizations to assign weights by themselves.

For example, enterprises with low AM maturity may have inadequate expertise and managerial support to identify which dimensions are the most relevant ones. On the other hand, the profile of the person responsible for identifying the weight vector most adequate to the organization may contain bias, e.g., someone with a technical profile may assign a value more related to operational than strategic dimensions. Thus, a study in greater depth of this issue would be needed to provide methods to support the assignment of weights.

In addition, the assessment procedure may support the application of other AMMMs. Then, it would be interesting to investigate the accuracy of AMAP assistance in AMMMs applications. On the other hand, the referential model is physical asset driven, which is an asset type. In this sense, it is opportune to investigate the application of AMAP involving other contexts, such as assets of emergent technologies and intangible assets.

AMAP focuses on a descriptive approach, which is adopted by most MMs in any managerial field. So, what stands out is the absence of prescriptive models, which could draw paths to improve the AM processes, thus creating value for the organization. In this context, the development and use of AMAP opens the opportunity to develop a prescriptive model. Then, future research can investigate what AM practices are adequate for AM dimensions, considering the AM maturity.

Moreover, the PLS-SEM application was based on only Brazilian enterprises. Taking into account this constraint, the sample can be increased, as well as adding enterprises from other countries. In addition, it would be interesting to incorporate other questions to assess business performance.

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Appendix A- AM dimensions proposed by GFMAM

Group	GFAM Dimension	AM decisions
Strategy & Planning	AM Policy	The principles and mandated requirements derived from and consistent with the organizational / corporate plan, providing a framework for the development and implementation of the asset management strategic plan and the setting of the asset management objectives.
	AM strategy and objectives	The strategic plan for the management of the assets of an organization that will be used to achieve the organizational / corporate objectives.
	Demand analysis	The processes an organization uses to both assess and influence the demand for, and level of service from, an organization's assets.
	Strategic planning	The processes an organization uses to undertake strategic asset management planning.
	AM Planning	The activities to develop the Asset Management plans that specify the detailed activities and resources, responsibilities and timescales and risks for the achievement of the asset management objectives.
Asset Management Decision-Making	Operation and 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.
	Resourcing strategy	Determining the activities and processes to be undertaken by an organization in order to procure and use people, plant, tools and materials to deliver the Asset Management Objectives and Asset Management Plan(s).
	Lifecycle value realisation	The activities undertaken by an organization to balance the costs and benefits of different renewal, maintenance, overhaul and disposal interventions.
	Capital investiment decision-making	The processes and decisions to evaluate and analyse scenarios for decisions related to capital investments of an organization.
	Shutdown and outage strategy	The activities taken by an organization to develop a strategy for shutdown and outages.
Asset information	Data e information Management	The data and information held within an organization's asset information systems and the processes for the management and governance of that data and information.
	Asset information standards	The specification of a consistent structure and format for collecting and storing asset Information and for reporting on the quality and accuracy of asset information.
	Asset information strategy	The strategic approach to the definition, collection, management, reporting and overall governance of asset information necessary to support the implementation of an organization's asset management strategy and objectives.
	Asset information systems	The asset information systems an organization has in place to support the asset management activities and decision-making processes in accordance with the Asset Information Strategy.
Lifecycle Delivery	Asset creation & Acquisition	An organization’s processes for the acquisition, installation and commissioning of assets.
	asset Decommissioning e Disposal	The processes used by an organization to decommission and dispose of assets due to ageing or changes in performance and capacity requirements.
	System engineering	An interdisciplinary, collaborative approach to derive, evolve and verify a life cycle balanced system solution which satisfies customer expectations and meets public acceptability.
	Technical standards e legislation	The processes used by an organization to ensure its asset management activities are compliant with the relevant technical standards and legislation.

	Configuration management	A management process for establishing and maintaining consistency of a product's physical and functional attributes with its design and operational information throughout its life.
	Reliability Engineering	The processes for ensuring that an item shall operate to a defined standard for a defined period of time in a defined environment.
	Resource Management	Implementing the Resourcing Strategy to manage the use of funds, people, plant, tools and materials in delivering asset management activities.
	Fault and Incident Response	Responding to failures and incidents in a systematic manner, including incident detection and identification, fault analysis, use of standard responses, temporary and permanent repairs as well as the taking over and handing back of sites.
	Asset operation	The processes used by an organization to operate its assets to achieve the business objectives.
	Shutdown and Outage Management	
	Maintenance delivery	The management of maintenance activities including both preventive and corrective maintenance management methodologies.
Organisation & People Collective decision making	Procurement e supply chain management	
	AM Leadership	The leadership of an organization required to promote a whole life asset management approach to deliver the organizational and Asset Management objectives of the organization.
	Competence management	The processes used by an organization 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
	Organizational culture	The culture of an organization in terms of its ability to deliver the organizational and Asset Management objectives.
	Organizational structure	The structure of an organization in terms of its ability to deliver the organizational and Asset Management objectives.
Risk & Review	Stakeholder Engagement	
	Sustainable development	
	Management of Change	
	Risk assessment e management	
	Management review, audit and assurance	
	Contigency planning and resilience analysis	
	Asset management system monitoring	
	Asset cost e valuation	
	Asset performance e health monitoring	

Appendix B- Asset management maturity questionnaire

Dimension	Questions	Level 0	Level 1	Level 2	Level 3	Level 4	Reference
AM Policy	To what extent has an asset management policy been documented, authorized and communicated?	The organization does not have a documented asset management policy.	The organization has an asset management policy, but it has not been authorized by senior management or is not influencing asset management.	The organization has an asset management policy, which was authorized by senior management, but had limited circulation. It can be used to influence strategy development and planning, but its effect is limited.	The asset management policy is authorized by senior management, is widely and effectively communicated to all employees and relevant stakeholders, and used to make these people aware of their asset-related obligations.	The organization has an Asset Management policy integrated into the organization, with its objectives documented, authorized, communicated and continuously improved.	Commerce Commission New Zealand (2011)
	To what extent does the asset management policy align with your organizational strategic plan and other organizational policies and other requirements, including mandatory, statutory and regulatory requirements to which the organization is committed?	The organization does not have an Asset Management Strategy and/or alignment with the entire government policy framework or strategy or corporate policy or objective.	The organization understands the need to align the asset management strategy with other organizational policies and strategies, as well as stakeholder requirements, and has begun to identify the linkages or incorporate them into the development of the asset management strategy.	The organization has demonstrated evidence of alignment with the entire government structure, corporate strategy, policy and objective. The work is quite advanced, but still incomplete.	The organization is fully aligned with the organization's entire governing structure, corporate strategy, policy and objective, overall risk management framework, and other organizational policies, including sustainability, relevant stakeholder requirements, and value for money.	The organization has an Asset Management Policy and Strategy fully integrated into the organization's business processes and subject to defined audit, review and update of the procedure sheet	Commerce Commission New Zealand (2011), Asset Institute (2021), Institute of Public Works Engineering Australasia
	How is policy in Asset Management managed, including the need for policy changes?'	The organization does not guarantee that its asset management is regularly reviewed and managed. Or the organization does not have an Asset Management policy	The organization is aware of the need to review and manage its Asset Management policy and has started working towards a regular but still incomplete review	The Asset Management policy is developed or modified by the senior management team and includes consultations with relevant stakeholders.	The Asset Management policy is developed or modified by the senior management team and includes consultations with relevant stakeholders.	The Asset Management policy is developed or modified by the senior management team and includes engagement with relevant stakeholders.	Commerce Commission New Zealand (2011), Asset Institute (2021)
AM Strategy and Objectives	How does the organization ensure that its asset management strategy is consistent with other organizational policies and strategies and the needs of stakeholders?	The organization does not consider the need to ensure that its asset management strategy is adequately aligned with the organization's other organizational policies and strategies or stakeholder requirements. OR The organization does not have an asset management strategy.	The need to align the asset management strategy with other organizational policies and strategies, as well as stakeholder requirements, is understood and work has begun to identify the linkages or incorporate them into the development of the asset management strategy.	Some of the linkages between long-term asset management strategy and other organizational policies, strategies and stakeholder requirements are defined, on which work is well advanced but still incomplete.	All links are in place and evidence is available to demonstrate that, where appropriate, the organization's asset management strategy is consistent with its other organizational policies and strategies. The organization has also identified and considered the requirements of relevant stakeholders.	The organization has ensured that the Management strategy is consistent with requirements, policies and strategies as part of the organizational routine, taking into account stakeholder requirements.	Commerce Commission New Zealand (2011)

	How does the organization establish its asset management strategy?	Asset management strategy is not widely agreed, accepted or applied and is not aligned with asset management objectives and policy.	The asset management strategy describes and develops a portfolio of assets to support service delivery.	The asset management strategy defines asset management priorities.	The asset management strategy performs a gap analysis to identify differences between existing and required assets and identifies asset-related risks that may affect service delivery.	The asset management strategy defines the asset performance levels required to achieve efficient service performance and provides the basis for the more detailed Asset Management Plans (acquisition plan, operations plan, maintenance plan and divestiture plan).	Asset Institute (2021)
	How does the organization's asset management strategy take into account the life cycle of assets, types of assets and asset systems under its management?	The organization does not consider the need to ensure that its asset management strategy is developed with due attention to the life cycle of the assets, asset types or asset systems it manages. OR The organization does not have an asset management strategy.	The need is understood and the organization is designing its asset management strategy to address the life cycle of its assets, asset types and asset systems.	Long-term asset management strategy takes into account the life cycle of some, but not all, of your assets, asset types, and asset systems.	Your asset management strategy takes into account the lifecycle of all your assets, asset types, and asset systems.	Your asset management strategy takes into account the lifecycle of all your assets, asset types, and asset systems. And, it uses optimization means to establish the Asset Management strategy.	Commerce Commission New Zealand (2011)
AM Planning	What processes do you have in place to develop an implementable asset management plan from your asset management policy and strategy?	The organization is unable to demonstrate that it has a strategic planning process.	The organization recognizes the need for a strategic planning process and intends to develop one.	The organization has basic processes in place to develop asset management plans based on the asset management policy and strategy. These are not consistent across all activities or businesses. This is a limited, linear process where policy and strategy inform the asset management plan.	The organization has a consistent approach to developing the asset management plan from the asset policy and strategy. This process is not just linear, with lessons learned at delivery also informing future planning. The line of sight on asset health and resilience is clearly understood by all teams across the company.	The asset management plan is integrated with your other plans. There is also clear evidence of links to wider actors and the impact of external constraints. The asset management plan adopts an adaptive approach with monitoring of performance indicators that determine when the investment should be made. It is continually updated as a result of identified gaps and lessons learned from realized and unrealized investment results.	Ofwat (2021)
	How does the organization develop and communicate, resource and execute its asset management plans?	The organization has a stated intention to develop asset management plans. OR the organization does not have asset management planning	Asset Management Plans contain basic information about assets, service levels, planned works and financial forecasts (5 to 10 years) and future improvements.	Asset management objectives are defined taking into account the strategic context. Approach to risk and critical assets described, top-down condition and performance assessment, future demand forecasts, description of supporting asset management processes, 10-year financial	Analysis of asset condition and performance trends (past/future), effective customer involvement in defining service levels, MDG, risk techniques applied to main programs. Strategic context analyzed with risks, problems and responses described.	Evidence of programs guided by comprehensive ODM techniques, risk management programs, and service level/cost trade-off analysis. Improvement programs are largely comprehensive with a focus on maintaining appropriate practices.	Institute of Public Works Engineering Australasia

				forecasts, 3-year asset management improvement plan.			
	How does the organization ensure that its asset management plan strikes an appropriate balance between short- and medium-term needs and long-term objectives?	The organization is unable to demonstrate that the asset management plan considers more than the price review period	The organization is aware of the need for the asset management plan to consider the short, medium and long term and there is evidence of plans for this.	The asset management plan considers trends in the integrity and resilience of assets over the medium term. Plans are in place to consider the impacts of investment delays on asset health and operational resilience on environmental, social and financial sustainability. The organization has a decision-making structure, but it is not applied consistently across the organization.	The asset management plan considers trends in the long-term health and resilience of assets. Trade-offs between short-term needs and long-term objectives and the impacts on the organization and customers are considered. The organization has a decision-making framework in place that considers whole-of-life costs and impacts on the organization and customers, and is applied consistently across the organization.	The asset management plan was developed using future scenarios related to asset integrity and operation resilience. Trade-offs between short-term needs and long-term objectives and impacts on environmental, social and financial sustainability are considered. The asset management plan adopts an adaptive approach with monitoring of performance indicators that guide when the investment should be made. The organization has a decision-making structure that considers broader values, such as natural capital and public value.	Commerce Commission New Zealand (2011)
Data e information Management	How does the organization maintain its asset management information system(s) and ensure that the data contained therein is of the required quality, accuracy and consistency?	There are no formal controls in place or the controls are extremely limited in scope and/or effectiveness.	The organization is aware of the need for effective controls and is in the process of developing appropriate control process(es).	The organization has developed controls that will ensure that the data held is of the required quality and accuracy and is consistent and is in the process of being implemented.	The organization has effective controls that ensure that the data maintained is of the required quality, accuracy and is consistent.	The organization has consolidated controls as part of its organizational culture that guarantee data quality and accuracy. And controls were regularly reviewed and improved where necessary.	Commerce Commission New Zealand (2011)
	What type of asset-related information does the organization collect and how does it ensure that the information is of the required quality (accuracy, consistency, reliability)?	The organization is aware of the need to collect asset data.	Basic physical information recorded in a spreadsheet or similar (e.g. location, size, type) but may be based on broad or incomplete assumptions.	Sufficient information to complete asset assessment (basic attributes, replacement cost, and asset age/life) and supports program prioritization (criticality). Documented asset hierarchy, identification and attribute systems. Metadata maintained as appropriate.	A reliable record of physical and financial attributes recorded in an information system with data analysis and reporting functionality. Systematic and documented data collection process in place. High level of confidence in critical asset data.	Information about type and cost of work history, condition, performance, etc. recorded at the asset component level. Systematic and fully optimized data collection program with supporting metadata.	Institute of Public Works Engineering Australasia
	How does the organization record asset information?	The organization had fragmented and incomplete component data, driven by	The organization had fragmented and incomplete component data, driven by	Component data is integrated with long-term financial needs.	Organization has complete component data driven by long-term operations,	The organization has data linked to long-term financial and service delivery needs,	Asset Institute (2021

		short-term operations and maintenance needs.	short-term operations and maintenance needs.		maintenance and financial needs, supports advanced ML decision making with minimal data set.	supports service level analysis with the required level of accuracy.	
Asset information Systems	What documentation does the organization establish to describe the key elements of its asset management system and the interactions between them?	The organization does not establish documentation that describes the main elements of the asset management system.	The organization is aware of the need to implement documentation and is in the process of determining how to document key elements of its asset management system.	The organization is in the process of documenting its asset management system and has documentation in place that describes some, but not all, of the key elements of its asset management system and their interaction.	The organization has established documentation that comprehensively describes all key elements of its asset management system and the interactions between them.	The organization has established a systematic and documented process/procedure to update key asset management elements whenever necessary.	Commerce Commission New Zealand (2011)
	What has the organization done to determine what its asset management information system(s) must contain to support its asset management system?	The organization has not considered what asset management information is required.	The organization is aware of the need to determine in a structured way what its asset information system must contain to support its asset management system and is in the process of deciding how to do this.	The organization has developed a structured process to determine what its asset information system must contain to support its asset management system and has begun implementing the process.	The organization has determined what its asset information system must contain to support its asset management system. The requirements concern the entire life cycle.	The organization uses a systematic and documented process that determines what the asset system should contain. The requirements concern the entire life cycle of the asset and the requirements of stakeholders.	Commerce Commission New Zealand (2011)
	How does your organization meet the information needs of those responsible for various aspects of asset management?	The organization intends to develop an electronic asset registry/AMIS.	The asset registry can record key asset attributes – size, material, location, age, etc. Asset information reports can be manually generated for AM Plan input.	The asset registry allows for hierarchical reporting (from component level to facility level). Customer service request tracking and planned maintenance functionality. The system allows the generation of manual reports for evaluation and renewal forecasting.	Spatial relationship capacity. More automated asset performance reporting across a wider range of information.	Financial, asset and customer service systems are integrated. And all advanced asset management functions are activated. Asset optimization analysis can be completed.	Institute of Public Works Engineering Australasia
AM Leadership	Has the organization clearly documented, understood and communicated the roles and responsibilities of positions?	The organization has not developed job descriptions	The organization is aware of the need to document roles and responsibilities and is in the process of determining how to document them.	The organization is in the process of documenting its job descriptions and has documentation in place that describes some, but not all,.	The organizational structure supports asset management. Roles reflect asset management resource requirements and are reflected in position descriptions for key roles. Consistent approach to asset management across the organization. Internal communication plan established.	Formal documented assessment of asset management capability and capacity requirements to achieve AM objectives. Demonstrable alignment between asset management objectives, asset management systems and individual responsibilities.	Government Property Profession (2014), sheet7
	To what degree does the organization's senior management	The organization's senior management did not consider the need to communicate the	The organization's senior management understands the need to communicate the	Senior management communicates the importance of meeting its asset	Senior management communicates the importance of meeting its asset	The ability of leadership to communicate the importance of meeting asset management	Commerce Commission New Zealand (2011)

	communicate the importance of meeting asset management requirements?	importance of meeting asset management requirements.	importance of meeting asset management requirements, but fails to do so.	management requirements, but only to parts of the organization.	management requirements to all relevant parties in the organization.	objectives is part of the organizational culture	
	How does the organization ensure leadership at all levels of the organization?	Leadership style at the operational level not aligned with leadership at the tactical and strategic level, lack of understanding and trust at all levels.	Senior management understands the benefits of asset management, but does not have a clear action plan or person to lead development.	Senior management supports asset management and communicates requirements. Development of processes and procedures between departments	The message is getting across and clear evidence of leadership up and down the Board level structure. Asset management is coordinated across functions.	The best communication methods prevailed from the strategic to the operational level, with leadership evident from the point of specialization. Clear support demonstrated by senior manager.	Asset Institute (2021
Competence Management	How does the organization ensure that people under its direct control who carry out activities related to asset management have an appropriate level of competence in terms of education, training or experience?	The organization did not recognize the need to assess the competence of the person(s) carrying out activities related to asset management.	The competence of personnel carrying out activities related to asset management is not managed or assessed in a structured way, beyond the formal requirements for legal compliance and security management.	The organization is in the process of implementing a means to assess the competency of person(s) involved in asset management activities, including contractors. There are gaps and inconsistencies.	Competency requirements are identified and assessed for all people who perform activities related to asset management - internal and contracted. Requirements are reviewed and staff reassessed at appropriate intervals aligned with asset management requirements.	Competency requirements are reviewed through the continuous competency assessment process, seeking to align competencies with the strategic requirements of asset management.	Commerce Commission New Zealand (2011)
	How does the organization identify competency requirements and then plan, deliver, and record the training needed to achieve the competencies?	The organization has no means of identifying competency requirements.	The organization recognized the need to identify competency requirements and then plan, provide and record the training necessary to achieve the competencies.	The organization has a process for identifying competency requirements aligned with the asset management plan(s) and then planning, delivering and recording appropriate training. It is incomplete or applied inconsistently.	Competency requirements are in place and aligned with the asset management plan(s). Plans are in place and effective in providing the training needed to achieve competencies. There is a structured means of recording the skills achieved.	Competency requirements are in place and aligned with the asset management plan(s) and future Asset Management requirements. Based on the competency records, training and educational programs are adopted to achieve the required competencies.	Commerce Commission New Zealand (2011)
	How does the organization identify and address any gaps in asset and resource management capabilities for its employees?	The organization cannot demonstrate how employee skill gaps in asset management are identified or addressed or that it has plans to address them.	The organization identified the importance of asset management competency for its employees and established a plan to identify gaps and improve employee competency. There is evidence of intention to progress this.	The organization has matrices of skills and competencies (or similar) for its functions related to asset management and resilience that are implemented through its job descriptions. The competence and capacity of the outsourced activity is monitored and reviewed as appropriate. There is resource tracking to ensure that there are sufficient resources to	The organization systematically identified any gaps and improvements in employee asset management competency. Functions across the organization were assessed against the need for asset management competency. The organization has a learning and development (or similar) path for asset management and resilience; and employees have personal training plans	All current competency gaps are identified by the organization with detailed plans to remediate or mitigate. Succession planning is carried out to identify future gaps in the organization with plans to remediate or mitigate them. There is consideration of future capabilities that may be required for improvements in managing asset integrity and	Ofwat (2021)

				carry out current asset management activities.	to improve their competence. There is resource tracking and forecasting to ensure there are sufficient resources to carry out current and future asset management activities. Potential triggers for the need for outsourcing are documented and relevant outsourced functions and activities are regularly monitored and reviewed for competence and capability	resilience and any emerging threats or opportunities.	
Risk assessment e management	How does the organization measure and manage the risks of its assets and asset management?	The organization takes an ad hoc approach to measuring and managing risk. Minimal evidence of risk management processes being documented.	Inconsistent approaches to risk management at different levels of the organization. The tactical and operational levels have their own documented risk measurement and management processes.	Risk management at the tactical and operational levels is based on a centrally defined documented process that is cognizant of the organization's policy for risk management and used consistently.	Risk management at strategic, tactical and operational levels is working effectively, is embedded and the value of risk management can be demonstrated. There is evidence of risk management process assessment procedures in place.	Risk management is part of the organizational culture and supports all decision-making through scenario planning in projects. There is evidence of continuous improvement.	Asset Institute (2021)
	How has the organization documented the process(es) and/or procedure(s) for identifying and evaluating assets and risks related to asset management throughout the asset lifecycle?	The organization did not consider the need to document process(es) and/or procedure(s) for the identification and assessment of assets and risks related to asset management throughout the asset lifecycle.	The organization is aware of the need to document asset-related risk management throughout the asset lifecycle. The organization has plans to formally document all relevant processes and procedures or has already begun this activity.	The organization is in the process of documenting the identification and assessment of asset-related risk across the asset lifecycle, but it is incomplete or there are inconsistencies between approaches and a lack of integration.	The identification and assessment of asset-related risk throughout the asset lifecycle is fully documented. The organization can demonstrate that appropriate documented mechanisms are integrated across lifecycle phases.	Risk assessment processes and procedures that take into account the asset's life cycle are being applied consistently. The organization seeks to update the process/procedure for risk identification and assessment, using new approaches and tools.	Commerce Commission New Zealand (2011)
	To what extent are risk management and resilience planning integrated into your asset management decision-making?	The organization has identified risk management as a future improvement.	The organization has developed a Risk Framework. Critical services and assets understood and considered by personnel involved in maintenance/renewal decisions.	Critical assets and high risks identified. Documented risk management strategies for critical assets and high risks.	Current resilience level assessed and improvements identified. Systematic risk analysis to assist in making important decisions. Risk register regularly monitored and reported. Risk managed and prioritized consistently across the organization.	Implemented resilience strategy and program, including defined service levels for resilience. A formal risk management policy in place. The risk is quantified and risk mitigation options evaluated. Risk is integrated into all aspects of decision making.	Institute of Public Works Engineering Australasia
Asset performance	How does the organization measure and manage the performance of its assets?	The organization understood the Condition and performance, but it was not quantified or documented.	The organization has adequate data and information to confirm current	Condition and performance information is suitable for use in planning short-term maintenance and renewals.	Future condition and performance information was modeled to assess whether asset management objectives	The type, quality and quantity of data have been optimized for the decisions being made. The underlying	Institute of Public Works Engineering Australasia

e health monitoring			performance against asset management objectives.		can be achieved over the long term. And contextual information, such as demand, is used to estimate likely performance.	data collection program is tailored to reflect the lifecycle stage of the assets.	
	How does the organization ensure that asset integrity is monitored?	The organization has not considered how to monitor the performance and condition of its assets.	The organization recognizes the need to monitor asset performance but has not developed a coherent approach. The measures are incomplete, predominantly reactive and delayed. There is no link to asset management objectives.	The organization is developing coherent asset performance monitoring linked to asset management objectives. There are reactive and proactive measures. Use is being made of leading indicators and analytics. Gaps and inconsistencies remain.	Consistent monitoring of asset performance linked to asset management objectives is in place and used universally, including reactive and proactive measures. Data quality management and review process are appropriate. Evidence of cutting-edge indicators and analytics.	The organization optimized asset performance monitoring, using information systems and advanced monitoring techniques in current time. Management reports based on the historical performance of assets and tools (risk, cost, etc.) support decision making	Commerce Commission New Zealand (2011)
	To what extent is asset performance aligned with organizational objectives?	Lack of reviews to assess asset and management performance to ensure alignment with asset management service delivery objectives	Absence of any formal process. Occasional ad hoc reviews undertaken by operational staff but not necessarily linked to or used by management to ensure alignment with asset management service delivery objectives.	Irregular or ad hoc reviews performed to evaluate asset and management performance to ensure alignment with asset management service delivery objectives.	Annual formal review process to evaluate asset and management performance to ensure alignment with asset management service delivery objectives. However, the results do not necessarily feed directly into annual budgets, long-term financial planning, and corporate and strategic planning.	Annual formal review process to evaluate asset and management performance to ensure alignment with asset management service delivery objectives. The results directly feed annual budgets, long-term financial planning and corporate and strategic planning.	Asset Institute (2021)
Asset cost e valuation	How does the organization understand the link and interdependencies between the health of assets and services in the short, medium and long term?	The organization fails to demonstrate that it understands the link between asset health and service.	The organization is aware of the need to understand the link between the health of assets and the service and there is evidence of the intention to progress in this direction.	The organization demonstrates that there is ad hoc consideration of the link between asset health and service for some types of assets or systems, with credible plans and resources to develop this further across the organization.	The organization has consistent processes for understanding the link between asset health and service across all types of assets and systems. The organization considers scenarios about how future asset health trends will impact asset performance, service, and performance indicators for different types of assets and systems. This understanding is used to inform investment planning.	The organization continually and systematically monitors, reports, and uses information about asset and service health to improve its understanding of the link between asset health and service. The organization incorporates new information about asset health trends to assess their impact on performance and adjusts its investment plans accordingly.	Ofwat (2021)
	How are the health and resilience of assets	The organization cannot demonstrate that it values the health and resilience of assets	The organization is aware of the need to value the health and resilience of assets when	The organization qualitatively considers the value of asset health and resilience when	The organization systematically and consistently quantifies (e.g.,	The organization has consistently and systematically implemented	Ofwat (2021)

	assessed when making investment decisions?	when making investment decisions and/or there is no evidence that it intends to do so.	making investment decisions and there are plans in place to progress in this regard.	making investment decisions; this is not done for all assets.	monetization) the value of asset health and resilience when making investment decisions. The organization has implemented and uses a value framework that covers a wide range of social, environmental and economic aspects.	its value framework across all areas of asset management and used it extensively to the point of monitoring the benefits obtained and improving the effectiveness of the value framework and decision support tool. The organization monetizes the holistic value of asset health and resilience in making investment decisions for the organization, customers, society and the environment, including ecosystem services/natural capital, carbon accounting and social capital.	
	How does the organization evaluate the delivery of value from assets?	Results are not evaluated to ensure they achieve objectives or generate value. Service levels have not been defined and confirmed through community consultation.	Results are not evaluated to ensure they achieve objectives or generate value. Service levels were developed and confirmed through community consultations.	Irregular and ad hoc assessment of whether or not assets are providing acceptable service levels based on formal, agreed service levels.	Formal process to evaluate whether or not the results and value delivered by assets satisfy formal and agreed service levels.	Formal process to assess whether or not results and value delivered by assets meet formal and agreed service levels, supported by formalized public assessment reports against service levels and community consultation to review service levels.	Asset Institute (2021)