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Research paper

An Artificial Intelligence maturity assessment framework based on international standards

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ABSTRACT

In an era dominated by technological integration, Artificial Intelligence (AI) is pivotal across various sectors, driving significant advancements and demanding robust quality measures for its implementations. This paper introduces a novel AI maturity assessment framework designed in alignment with International Standards provided by ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission), specifically with the ISO/IEC 33000 family of standards for process assessment. Our framework aims to provide AI system developers with a structured tool for continuous improvement of their development processes, thereby enhancing the reliability and efficacy of AI applications. To demonstrate the applicability of our proposed framework, we have validated it through a case study in the automotive sector. Specifically, the framework was employed to assess and enhance an AI project to develop a mechanism to determine vehicle behavior from sensor data within the constraints of onboard devices. Our findings identify key improvement points contributing to the iterative enhancement of AI system quality in engineering applications.

1. Introduction

Artificial Intelligence (AI) has become a fundamental technology in today's society, and this has been reflected in recent years as it has become increasingly common to see people using tools that employ AI techniques in their daily lives. In recent years, this discipline has made its way into different areas of society, such as medicine (Wang and Preininger, 2019) or business intelligence (Enholm et al., 2022).

It is remarkable the new digital transformation that AI is causing and the impact it is having on the world, even compared to the industrial and digital revolutions (Makridakis, 2017). Moving to the business world, more and more organizations are looking to use AI to gain an advantage over their competitors and gain value. By 2030, AI is expected to contribute $15.7 trillion to the global economy, equivalent to a 14% increase in global GDP (Anand and Verweij, 2017).

However, as in other computing fields, the development of AI software tools involves certain particularities, such as additional risks and challenges to those already present in traditional software development, which must be studied and considered throughout these developments. Studies such as the European Commission's "White Paper On Artificial Intelligence - A European approach to excellence and trust" (European Commission, 2020) already address this concern for establishing regulatory frameworks and standards that promote responsible and high-quality development on the AI field. It is worth noting that in today's society, and in particular the institutions, some of their objectives are already being focused on mitigating this lack of regulation in the field of AI. This is the case of the European Union (EU), which has become the first major institution in the world to agree on a comprehensive regulatory proposal on AI: the "EU AI Act" (European Commission, 2021).

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) are already making progress in establishing an international AI regulation. Works such as the recent ISO/IEC 25059 "Quality model for AI systems" standard (ISO, 2023a) or (Oviedo et al., 2024), which proposes an environment to assess the suitability of AI systems, have made advances in quality AI product regulation. Nevertheless, it is necessary to create frameworks directly focused on companies to help them in their AI software processes. Furthermore, two standards are worthy of particular note for offering a structure and tools for the enhancement of organizational processes, the Capability Maturity Model Integration (CMMI) v3.0 (CMMI Institute, 2023) and the ISO/IEC 33000 family (ISO, 2015a), former ISO/IEC 15504, better known as Software

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Table 1
Comparison of AI-related process assessment frameworks and standards.

Works/Standards	Type	AI-Specific	Disadvantages and limitations
CMMI v3.0 (CMMI Institute, 2023) A process assessment framework that assists organizations beyond software engineering to understand their current level of capability and performance, providing a roadmap to optimize business outcomes.	Widespread American model	–	According to some research, as in Garzás et al. (2013) or Staples et al. (2007), the model has high costs in terms of effort and money. It is focused on very large companies due to its long implementation times, which require a high investment that small and medium-sized companies cannot afford.
ISO/IEC 33000 (ISO, 2015a) A software process assessment framework and continuous process improvement, replacing ISO/IEC 15504, better known as Software Process Improvement and Capability dEtermination (SPICE).	International Standard	–	A generic framework that is widely used, but does not establish particularities for any sector, which defines process quality assessment and measurement requirements. Furthermore, it not specify evaluation elements or focus on AI-specific issues.
ISO/IEC/IEEE 12207 (ISO, 2017a) A process reference model focusing on lifecycle processes for software systems development and maintenance.	International Standard	–	Does not consider processes, activities, and outcomes specific to AI development.
MMIS v2.0 (Rodriguez et al., 2021) A framework for assessing and improving development process quality, compliant with ISO/IEC 33000 and ISO/IEC 12207.	Practical model for maturity assessment and improvement	–	Focuses on the software systems development life cycle, but does not include the specific processes used in the development of AI systems.
ISO/IEC 5338 (ISO, 2023b) A process reference model focusing on AI system development lifecycle processes, extending generic international standards to AI systems.	International Standard	Included	Does not determine the assessment process, measurement framework, or maturity levels to be used for the processes defined on the standard.

Process Improvement and Capability dEtermination (SPICE). While both standards are compliant, this paper uses the ISO/IEC 33000 family, due to its international character and the complexity and high cost of the CMMI model for the companies that apply it (Rodriguez et al., 2021). In recent years, standards and models have emerged to help companies continuously improve their software processes, such as the ISO/IEC/IEEE 12207 “Software life cycle processes” (ISO, 2017a) or MMIS (Software Engineering Maturity Model) v2.0 (Rodriguez et al., 2021). While these models offer valuable guidelines, they do not fully address AI-specific challenges, tasks, roles and processes, and they have to be tackled directly for the improvement of development quality. This is the case of the recent publication of the ISO/IEC 5338 standard (ISO, 2023b). This standard aims to identify and define a reference model for process improvement on the AI field.

Table 1 provides an overview of the relevant standards and process assessment models, their involvement with AI systems and their weaknesses.

This paper sets out to create an AI maturity assessment framework, based on the ISO/IEC 33000 (ISO, 2015a) standards family and the ISO/IEC 5338, known as Artificial Intelligence Software Maturity Model (MMSIA by its Spanish acronym), which can be implemented (either in particular projects or in the overall organization) to improve the quality of the processes necessary for the development of such systems. The result will be AI systems with a high enough level of quality to satisfy the customer needs and with adequate efficiency. The proposed framework has been validated through a detailed case study in the automotive sector to demonstrate its utility and applicability. Specifically, the framework was applied to assess and refine an AI project focused on developing a mechanism to deduce the kinematic state of a vehicle using sensor data. The chosen project’s engineering profile emphasizes the AI system’s adaptation to the computational constraints of onboard devices by implementing an approach to processing sensor data using different neural network architectures.

The remainder of the paper is organized as follows. The next section presents more detail of ISO/IEC 33000 and ISO/IEC 5338. The developed framework is based on these. Section 3 summarizes the proposed MMSIA model, indicating the processes involved and the different maturity levels. Section 4 describes in detail the validation performed to verify the feasibility of the model through a case study in the automotive sector. Finally, the last sections present the lessons learned, conclusions, and future work.

2. Background

The MMSIA maturity model presented in this paper is based on the framework provided by the ISO/IEC 33000 family of standards, which specifies how to carry out the maturity assessment process, and the ISO/IEC 5338 process reference model, which specifies which AI software lifecycle processes are implemented and evaluated. In this way, an organizational maturity model, which does not yet exist in the literature, of the AI system development lifecycle is defined. This provides a more practical, enterprise-focused model, specialized in the particular characteristics that are introduced in the development of AI systems, which allows AI organizations to assess and measure their level of AI development maturity. Both international standards on which the MMSIA model is based are detailed below.

2.1. ISO/IEC 5338: AI system life cycle processes

The new ISO/IEC 5338 standard “AI system life cycle processes” was published in December 2023. It is intended to be a process reference model for AI. The standard provides a set of processes to define, control, manage, implement and improve AI systems throughout the different stages of their life cycle. An overview of the processes listed in ISO/IEC 5338 is shown in Fig. 1.

These processes can be applied within an organization, in general, or in a particular project. ISO/IEC 5338 consolidates other standards that are generally applicable to software and systems development, including ISO/IEC/IEEE 15288 “System life cycle processes” (ISO, 2023c) and ISO/IEC/IEEE 12207, whose processes have been integrated for this new standard. It also consolidates other standards that are more specific to the field of AI: ISO/IEC 22989 “Artificial intelligence concepts and terminology” (ISO, 2022a) and ISO/IEC 23053 “Framework for Artificial Intelligence (AI) Systems Using Machine Learning (ML)” (ISO, 2022b), which define the specific concepts of AI development, together with a framework that describes the components and functions involved in the development of AI systems, respectively. These last two standards have been used to incorporate new processes that are specific to AI and to modify existing processes in ISO/IEC/IEEE 12207 by incorporating key aspects and concepts of this domain.

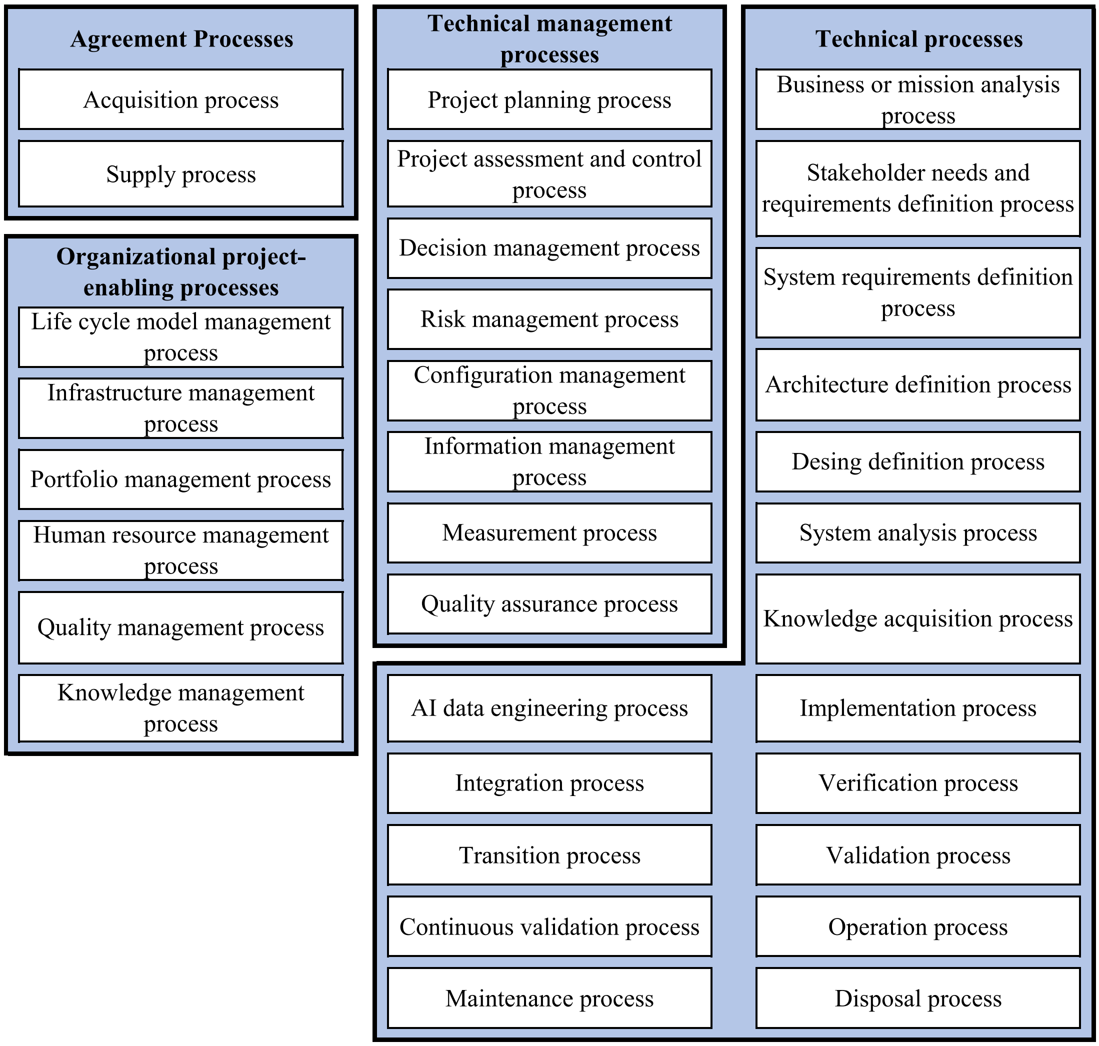

Fig. 1. Overview of processes according to ISO/IEC 5338 (ISO, 2023b).

ISO/IEC 5338 defines 33 processes that, as in ISO/IEC/IEEE 12207, have been grouped into four large groups according to a set of aspects that organizations developing AI systems must consider.

These aspects range from the management of different elements involved in the development to the support, including the evaluation of the performance of the processes themselves. This gives rise to a classification of processes based on the organizational objectives they provide. The following groups of processes are defined: Agreement Processes, Organizational Project-Enabling Processes, Technical Management Processes and Technical Processes.

As a result, a reference model of processes for the development of quality AI systems is established. However, a model that is intended to help companies developing AI systems to evaluate and continuously improve these defined processes requires the use of other standards that define how to carry out the evaluation and assurance of these processes. The ISO/IEC 33000 family provides the guidelines to define a maturity model based on a process reference model.

2.2. ISO/IEC 33000 family

The ISO/IEC 33000 series of standards defines a coherent framework for assessing the quality of software processes within an organization. This standard defines a framework for assessing organizational maturity, defined as the degree to which an organization has established a set of predefined processes according to a standard within a domain that will help to achieve a set of business objectives.

In this way, ISO/IEC 33000 allows the evaluation of organizations according to a set of organizational maturity levels. Each level consists of a set of general and specific best practices related to predefined processes that will help improve the organization's performance. The structured approach provided by this set of standards offers companies the opportunity to achieve various organizational objectives:

- To know the status of the processes established within the organization seeking continuous improvement.
- To know the capability of the processes established within the organization for a requirement or a set of them.
- To know the capability of the processes needed for a specific contract.

Thus, ISO/IEC 33000 aims to provide organizations with the tools to know their status and help them to continuously improve their processes within a specific domain, such as the development of AI systems and the processes required for this purpose.

2.2.1. Overview of the ISO/IEC 33000 series

The ISO/IEC 33000 family focuses on process assessment, establishing a three-component architecture for this purpose:

- Assessment Process: provides a detailed description of the steps to be followed in an assessment.

- Measurement Frameworks: provides ratings for measuring specific process quality attributes (such as process capability).
- Process Models: provides the set of processes that represent the entities under evaluation. The MMSIA model uses the processes defined in ISO/IEC 5338.

The ISO/IEC 33000 series comprises several more specific standards. An overview of the architecture and its elements is presented in Fig. 2. Some of the main standards in this family are the following:

- ISO/IEC 33001: Process assessment — Concepts and terminology (ISO, 2015b), offering a glossary of concepts related to process assessment and describing how the various parts of the family of standards fit together.
- ISO/IEC 33002: Process assessment — Requirements for performing process assessment (ISO, 2015c). This standard sets out the requirements for process assessment. It ensures the coherence and repeatability of values and results during the assessment.
- ISO/IEC 33003: Process assessment — Requirements for process measurement frameworks (ISO, 2015d). This standard establishes the requirements applicable to the process measurement frameworks that support the assessment of process quality characteristics.
- ISO/IEC 33004: Process assessment — Requirements for process reference, process assessment and maturity models (ISO, 2015e). This standard establishes the requirements for creating and verifying process reference, assessment and maturity models.
- ISO/IEC TR 33014: Process assessment — Guide for process improvement (ISO, 2013). This standard informs about the use of process assessment for carrying out process improvement in a continuous improvement framework.
- ISO/IEC 33020: Process assessment — Process measurement framework for assessment of process capability (ISO, 2019). This standard defines a process measurement framework that supports the process capability assessment according to the requirements in ISO/IEC 33003.
- ISO/IEC TS 33030: Process assessment — An exemplary documented assessment process (ISO, 2017b). This technical specification provides an example of an assessment process, with guidelines about the required activities for this process.

2.2.2. Assessment process with ISO/IEC 33000

One of the most essential aspects of assessing the processes of an organization using the ISO/IEC 33000 family is to measure the level of capability of each process. Assessing the capability of a software process means determining the level at which a process is implemented in an organization. To measure the capability of a process, a series of Process Attributes (PAs) are used, which represent elements that allow to evaluate, individually, a specific aspect of the capabilities and aptitudes of a process. These attributes are transversal and apply to all processes. These attributes are composed of management practices and generic work products. These elements represent the process capability indicators, through which their individual measurement is performed to determine the degree of attainment of the attribute and, therefore, the level of capability of the process to be evaluated. Table 2 below shows these capability levels and the corresponding process attributes defined by ISO/IEC 33020.

In order to qualify the capability level of a process, it is necessary to know the anatomy of a process. In this way, two parts have to be considered for the capability assessment of a process:

- Specific part: this is directly related to capability level 1, and the PA 1.1 Process performance attribute. To assess this part, it is necessary to consider the particular results of the evaluated process and to check whether these observable results are achieved by the Outcomes (OC) defined in the process reference model for each process.
- Generic part: it is related to capability levels 2 to 5, i.e., it evaluates the remaining process attributes (PA 2.1 to PA 5.1). To assess this part, it is necessary to consider the specific generic practices defined for each process attribute and to verify the performance of these practices by achieving observable results.

An assessment of the capability level of a particular process can be made from the outcomes and the results of the process attributes observed in the assessment of each of the process attributes of the process under evaluation.

2.2.3. ISO/IEC 33000 application

The ISO/IEC 33000 family of standards has been used in a wide range of academic works (either in its current version, or with the superseded SPICE) for different sectors and applications: service management (Feversani et al., 2023); the automotive industry (Winz et al., 2020); agile software development assessment (Özcan-Top and Demirors, 2019); usability (Lacerda and von Wangenheim, 2018); testing (Dussa-Zieger et al., 2017); data quality and governance (Carretero et al., 2017; Caballero et al., 2023); disaster management, for measuring process management capability (Chroust, 2018); and Green Information Technology, as a basis for a framework for governance and management (Patón-Romero et al., 2019a,b).

The case study presented in del Carpio (2018) is worth mentioning, since it proposes a visual tracing of the ISO/IEC 33000 assessment framework through a multi-layer representation model that describes the standard in a practical way. Finally, equally worthy of note is our proposal called MMIS (Rodriguez et al., 2021), for which a second version has been issued, which presents a maturity model based on the ISO/IEC 33000 series for improving the quality of the software development life cycle processes, and which has already been applied in more than 20 companies of different sizes. At present, however, there is no in-depth evaluation of the use of the ISO/IEC 33000 standard to assess and improve AI system development lifecycle processes in order to improve the quality of AI systems.

3. MMSIA: Artificial intelligence software maturity model

This section presents the MMSIA model we have developed, based on ISO/IEC 33000 and ISO/IEC 5338, which aims to provide companies developing AI systems with a framework for evaluating and improving their processes involved in the development lifecycle of these systems. The MMSIA model does not replace the ISO/IEC 5338 standards and the ISO/IEC 33000 family of standards, but rather seeks to use the process measurement and assessment methods proposed by ISO/IEC 33000, and the processes defined in AI systems development lifecycle by ISO/IEC 5338, to enable companies developing AI systems to assess their maturity level of AI development. The proposed model is based on the following points of interest:

- The new ISO/IEC 5338 standard provides a reference model for the lifecycle processes of AI systems.
- The process capability and organizational maturity assessment model proposed by ISO/IEC 33000 family.

Moreover, the authors have experience in the development of maturity models, as reflected in the MMIS model (Rodriguez et al., 2021), which is used for the assessment of traditional software system development processes, using the ISO/IEC/IEEE 12207. In a similar way, the MMSIA model has been developed for the assessment of AI system development processes by using ISO/IEC 5338 as the process reference model. Therefore, one of the first steps in the definition of MMSIA was the analysis of the differences between these two reference models, which produced the following findings:

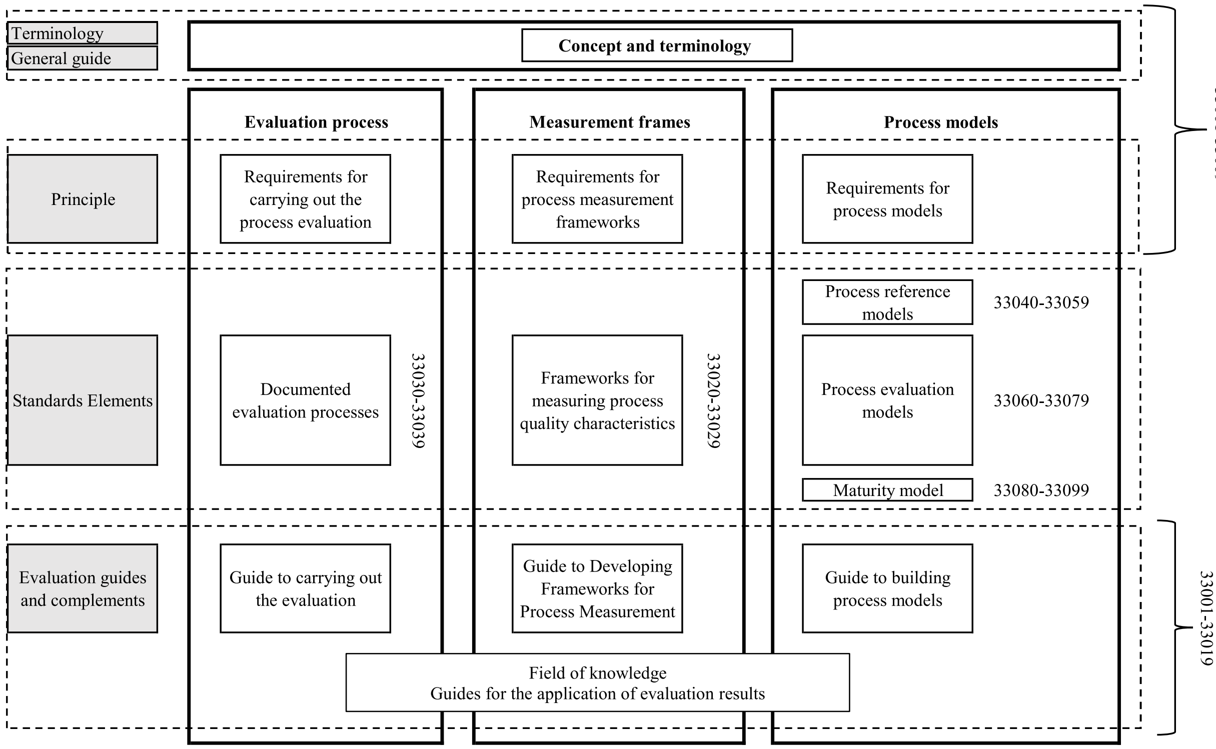

Fig. 2. Overview of the ISO/IEC 33000 family structure.

Table 2
Capability levels and process attributes.

Capability level	Key PA	Process attribute (PA)
Level 0. Incomplete Process	–	–
Level 1. Performed Process	PA 1.1	Process performance
Level 2. Managed Process	PA 2.1	Performance management
	PA 2.2	Document information management
Level 3. Established Process	PA 3.1	Process definition
	PA 3.2	Process deployment
	PA 3.3	Process assurance
Level 4. Predictable Process	PA 4.1	Quantitative analysis
	PA 4.2	Quantitative control
Level 5. Innovating Process	PA 5.1	Process innovation

- ISO/IEC 5338 incorporates three new processes specific to the development of AI systems: the Knowledge Acquisition Process (a process that provides the ways to obtain the knowledge for the AI system); the AI Data Engineering Process (a process that prepares, formats and obtains the data sets used in the development of the AI system); and the Continuous Validation Process (a process that seeks to ensure that the AI system continues to perform appropriately after the system has been developed).
- 7 processes from ISO/IEC/IEEE 12207 are unchanged and can be directly applied in ISO/IEC 5338.
- 23 processes from ISO/IEC/IEEE 12207 have been modified by adding, deleting, or changing some of their elements to adapt them to the particularities of AI.

Once the analysis of the ISO/IEC 5338 standard has been carried out, it is necessary to trace the processes in the model to the organizational maturity levels so that an incremental and continuous process improvement can be achieved. It should be noted that not all processes have been incorporated to MMSIA. Only the subset of processes that have been identified as fundamental to the development of AI systems throughout the lifecycle (from the identification of customer needs to the delivery of the final product) will be used. Specifically, Table 3 shows the different maturity levels of the MMSIA model and the processes from the reference model that were assigned to each of them:

The construction of this MMSIA model, with the development of the necessary relationships between the AI process reference model, the process assessment model, and the maturity model defined in the table above, has been carried out according to the requirements provided by ISO/IEC 33004. For each process of the reference model defined above, the following attributes have been described: purpose, process results, activities and work products. In this way, the guidelines for assessing the processes' quality and the corresponding capability level are defined for each process. For example, Appendix A of this paper shows the features for the AI Data Engineering Process.

Thus, once the different processes to be assessed and their features had been established in the MMSIA model (Table 3), the assessment process with its several steps was defined. This process begins with a documentary review of the different elements involved in the development of the AI systems that are being assessed, which is carried out through a series of interviews with the various people involved in the development of these systems. The result of these interviews will be a set of evidences and observations that will be related to the characteristics of the processes evaluated in the MMSIA model and their degree of implementation in the organization. Based on this evidence, a stage is then carried out to assess the level of capability of each of the processes involved. For this purpose, the process attributes, as defined in ISO/IEC 33020, and the individual outcomes used for PA 1.1 are used. By

Table 3
MMSIA maturity levels.

Maturity level	Defined processes
Level 1: Basic	Project Planning Process, Implementation Process and AI Data Engineering Process
Level 2: Managed	Supply Process, Life Cycle Model Management Process, Quality Assurance Process, Project Assessment and Control Process, Measurement Process, Configuration Management Process, Stakeholder Needs and Requirements Definition Process and Knowledge Acquisition Process
Level 3: Established	Infrastructure Management Process, Human Resources Management Process, Decision Management Process, Risk Management Process, Architecture Definition Process, Integration Process, Verification Process, Validation Process, System Requirements Definition Process and Continuous Validation Process
Level 4: Predictable	Portfolio Management Process
Level 5: Innovative	Knowledge Management Process and Business Analysis Process

Table 4
Qualification nomenclature for outcomes and process attributes.

Key	Rating	Definition
N	Not achieved	There is little or no evidence of achievement of the defined outcome in the evaluated process.
P	Partially achieved	There is some evidence of focusing and achieving the defined outcome in the process being evaluated. Some aspects of the achievement of the process attribute may be unpredictable.
L	Largely achieved	There is evidence of a systematic approach and significant achievement of the defined outcome in the evaluated process. There may exist some deficiencies related to this attribute of the process in the evaluated process.
F	Fully achieved	There is evidence of a comprehensive and systematic approach and full achievement of the defined outcome in the evaluated process. There are no significant weaknesses related to this attribute of the process in the evaluated process.

Table 5
Process attribute qualification method.

Key	Rating	Definition
N	Not implemented	The degree of implementation of the outcomes of the process is from 0% to 15%.
P	Partially implemented	The degree of implementation of the outcomes of the process is from 16% to 50%.
L	Largely implemented	The degree of implementation of the outcomes of the process is from 51% to 85%.
F	Fully implemented	The degree of implementation of the process outcomes is from 86% to 100%.

way of explanation, each process attribute is a measurable property of the process capability within this process measurement framework. Consequently, the process attribute assessment is a judgment on the degree to which the process attribute has been achieved in the process being assessed. Accordingly, a process attribute or outcome is measured using an ordinal scale, and the nomenclature used for the qualification is described in Table 4.

The qualification of the process attributes, at a general level, follows the same nomenclature as above. Its value is derived from the qualification of all the outcomes of each process and the process attribute results, according to the criteria shown in Table 5.

Finally, to obtain the value of each process's capability level, an aggregation method is used based on criteria similar to the following: a process is at capability level X if all process attributes of the previous levels have a rating of "fully implemented" (F) and the process attributes in capability level X have a rating of at least "largely implemented" (L).

Once the capability levels of an organization's processes have been calculated, the organizational maturity assessment is carried out. This evaluation consists of determining the degree to which an organization carries out the necessary processes to contribute to the fulfillment of its business objectives in an AI development environment. By using the process profiles defined for each of the maturity levels indicated above, it is possible to represent organizational behaviors and help in the continuous and incremental improvement of the processes. However, to define a maturity level for an organization, it is necessary to establish a correspondence between the capability levels for the processes and the maturity levels for the organization. For this reason, the following derivation rules are defined in MMSIA:

- To achieve maturity level 1 (basic), all processes included in maturity level 1 must be at capability level 1, ensuring compliance with process attribute PA 1.1, thus demonstrating the achievement of the purpose of these processes.
- To achieve maturity level 2 (managed), all processes included up to maturity level 2 must be at capability level 2, ensuring compliance with process attributes PA 1.1, PA 2.1 and PA 2.2, thus demonstrating management of the execution of these processes and associated work products.
- To achieve maturity level 3 (established), all processes included up to maturity level 3 must be at capability level 3, ensuring compliance with process attributes PA 1.1, PA 2.1, PA 2.2, PA 3.1 and PA 3.2, demonstrating the effective definition, improvement, deployment and assurance of these processes.
- To achieve maturity level 4 (predictable), all processes included up to maturity level 4 must be at capability level 3, ensuring compliance with process attributes PA 1.1, PA 2.1, PA 2.2, PA 3.1 and PA 3.2, and, in addition, the set of processes that the organization selects to be controlled quantitatively, in alignment to their business objectives, must achieve capability level 4, also ensuring compliance with process attributes PA 4.1 and PA 4.2. This way, an effective analysis and quantitative control of the fundamental processes for achieving the business objectives is demonstrated.
- To achieve maturity level 5 (innovated), all processes included up to maturity level 5 must be at capability level 3, ensuring compliance with process attributes PA 1.1, PA 2.1, PA 2.2, PA 3.1 and PA 3.2, and, in addition, the set of processes that the organization selects to be controlled quantitatively and innovated due to their alignment to business objectives, must achieve capability level 5, also ensuring compliance with process attributes PA 4.1, PA 4.2,

PA 5.1 and PA 5.2. In this way, innovation is demonstrated in the processes and their corresponding implementation of innovation in the processes that are considered fundamental to achieving the business objectives.

To sum up, the MMSIA model defined in this section allows companies developing AI systems to assess the processes involved in their workflows, thus allowing them to determine a baseline for continuous and incremental improvement. This, in turn, makes it possible to achieve productive and quality AI systems and models, and to ensure the satisfaction of customers and users at all times. In order to validate the model presented, a case study was carried out in the real environment of an AI development project, which is presented below.

4. Model verification and validation

This paper defines a model to assist companies in assessing and continuously improving the processes used during the AI system development life cycle. A series of standards have been established to provide the context for the unified application of the MMSIA model. On the one hand, a standard directly focused on the AI development life cycle, the ISO/IEC 5338 standard, has been used as the process reference model, and its applicability in the model has been analyzed and studied for each process. In addition, the measurement and evaluation model has been established to provide the required tools to assess the different elements involved in the processes and to determine the level at which the processes are established in an organization, all supported by the ISO/IEC 33000 family. Finally, a maturity model has been created that fulfills the objective of providing the model with a gradual process of continuous improvement of the quality of the processes of the evaluated organizations.

Once the MMSIA model was defined to evaluate and improve the processes used to develop various AI systems, its validation was carried out in a real-world setting to provide a practical perspective on its applicability. This validation was conducted in collaboration with a Spanish company specializing in technological solutions that employ diverse AI tools and techniques. The focus was a project within the automotive sector, aiming to deliver an AI-based solution to detect a vehicle's kinematic state using accelerometer data. While several organizations contributed to the overall project, the evaluated company was responsible for developing the AI modeling component.

The AI system addressed some challenges in real-time data processing under the constraints of onboard devices, such as limited computational power and memory. The company implemented a series of neural network architectures, including convolutional and recurrent neural networks, to effectively process temporal accelerometer data. These architectures were chosen for their ability to capture both spatial and sequential features, ensuring optimal model performance. Additionally, various preprocessing techniques, such as noise filtering, normalization, and feature engineering, were applied to the accelerometer data to enhance data quality and model robustness.

This case study exemplifies the application of AI in engineering by addressing the complexities of processing dynamic data in real-time, balancing computational constraints, and ensuring robust, high-performing solutions for safety-critical systems. The aim is to demonstrate the MMSIA framework's practical utility and provide actionable insights for improving AI project development processes in engineering environments through this framework.

The evaluation process was carried out by interviewing some of the people involved in the development of the AI model in order to learn about their development and management procedures. Although other stakeholders were involved in the project, such as customers, managers or employees, their activities were implicitly reflected in some of the processes involved in the development. Therefore, through these interviews, it has been possible to acquire a global vision of how the MMSIA model processes are implemented in the project, as well as the main difficulties they faced and the solutions they implemented. In addition, the authors have studied and evaluated a series of documentary evidence regarding the implementation of the processes involved in the development of the AI model, as well as a survey to gather different information on the processes implemented.

This section will first present the details of the evaluation carried out. The results obtained along with the strengths and weaknesses detected will be presented. Finally, a summary with some points for improvement will be provided.

4.1. Evaluation criteria

The assessment was based on the ISO/IEC 33000 standard, and specifically the maturity level 3 according to the MMSIA model defined in this paper, establishing the following 21 processes as shown in Table 6.

As the table above shows, the processes have been grouped according to the first three maturity levels defined in the MMSIA model: Basic, Managed and Established.

The strengths and weaknesses identified for each maturity level, which become opportunities for process improvement, are then presented in the following subsection. In addition, the qualification result obtained for each process included in each maturity level is indicated. In some cases, the "–" symbol indicates that the process attribute or outcome is not applicable to the project under evaluation. For more details, we offer all the evaluation results in Appendix B.

The qualification of each process is derived from the qualification method defined above in the MMSIA section and uses the nomenclature defined therein. In turn, the qualification of these expected process results is based on the evaluator's judgment on their fulfillment, for which the findings detected in the evaluation are considered.

4.2. Evaluation results

This section presents the comprehensive evaluation results of the AI maturity assessment framework applied across different organizational maturity levels — Basic, Managed, and Established. Although we present the results of the processes grouped by the level they correspond to, all processes have been evaluated for the target level of capability/maturity (level 3). The analysis highlights the strengths and identifies potential areas for improvement.

4.2.1. Maturity level 1: Basic

The first level of maturity encompasses key processes such as Project Planning, Data Engineering, and Implementation. Regarding the planning phase of the case study, the project followed the CRISP-DM methodology (Schröer et al., 2021), structured into distinct blocks further divided into multiple sprints. The first step was the identification of suitable AI techniques, guided by a review of the literature on similar case studies. This step ensured alignment with both the project's objectives and system constraints. At the same time, significant attention was dedicated to the data engineering process. Original data was preprocessed using different techniques, resulting in datasets ready for model consumption. Target labeling and exploratory analysis were conducted to extract the necessary insights for addressing the problem. The data preparation process also prioritized traceability, capturing detailed records of the time, format, and source of data collection. The resulting datasets were balanced and unbiased for training and testing, with an additional validation set to support robust model evaluation and refinement. Finally, the implementation iterative development process produces deliverables such as functional code, models, and comprehensive documentation. Hyperparameter optimization was methodically carried out to maximize the performance within the system's constraints. Additionally, the project code was documented, with comments and supplementary materials ensuring transparency and traceability.

A number of strengths were identified in the processes evaluated at this level of maturity:

Table 6
Maturity levels and processes evaluated.

Maturity level	Process	Key process
Level 1: Basic	Project Planning	PP
	Implementation	IMP
	AI Data Engineering	AIDE
Level 2: Managed	Supply	SUP
	Stakeholder Needs and Requirements Definition	SNRD
	Life Cycle Model Management	LCMM
	Project Assessment and Control	PAC
	Quality Assurance	QA
	Measurement	MEA
	Configuration Management	CM
	Knowledge Acquisition	KA
Level 3: Established	System Requirements Definition	SRD
	Infrastructure Management	IM
	Human Resources Management	HRM
	Decision Management	DM
	Risk Management	RM
	Architecture Definition	AD
	Integration	INT
	Verification	VER
	Validation	VAL
	Continuous Validation	CV

Table 7
Results of the maturity level 1 processes assessment.

Process	Rating
Project Planning (PP)	L
Implementation (IMP)	L
AI Data Engineering (AIDE)	F

- The study was conducted through an exhaustive search for the best AI techniques to solve the problem.
- The model optimization was carried out through a complete hyper-parameters process.
- The process of data collection, handling, pre-processing and preparation can be highlighted as one of the most complete of the whole project and a strength to be taken into account.

However, there are some weaknesses that should be addressed in order to try to achieve some opportunities for improvement:

- There is no assessment of the workload and no subsequent analysis.
- No coding standard is defined to be followed, neither its subsequent verification nor its compliance.
- No direct traceability exists between the code generated and their developers, or with the requirements.
- The use of diagrams and specific documentation about the data processing and modeling tasks is necessary.

The weaknesses identified branch from the development team's lack of experience in implementing established software engineering practices. These weaknesses lead to inefficiencies in resource allocation, knowledge gaps and concerns about consistency and compliance. Addressing these opportunities requires targeted actions to enhance overall efficiency, such as implementing a suitable effort estimation framework adapted to the project's complexity, defining the coding standards in the corresponding documentation, and introducing the use of tools like requirement management and control version systems. In addition, including detailed diagrams and documentation on data handling would help close knowledge gaps, increase transparency and improve the reproducibility of the product (see Table 7).

4.2.2. Maturity level 2: Managed

The second maturity level includes the evaluation of processes directly related to requirements management. The first phase of the project involves understanding the scope of the business, in which some characteristics, conditions and limitations that the project or the future model may have are captured. These requirements have been defined through interviews with the client and with the transfer and review of documentation and project reports. Also, several lines of work have been defined in the project, and in each one, different AI techniques have been executed to build the model. As for the monitoring of the project, several meetings were held in which the client was involved, and certain decisions were taken.

With regard to quality measurements in the project, a series of indicators or parameters directly related to the development of the model have been used, such as execution time, model size, number of operations, accuracy, and number of parameters to be trained. The results of these parameters have been stored, analyzed and interpreted for decision-making. However, it should be noted that although the project has had some of them, there are no formal indicators defined for quality assurance in the different lifecycle processes that are reviewed, evaluated and managed throughout the development. In terms of configuration management, no fully defined or established formal configuration management process has been detected. Furthermore, no tool has been used to manage the configuration of the project elements. On the other hand, some configuration criteria have been established for some elements, such as using specific nomenclature for the deliverable models and rudimentary version control tools for the code and documentation. Finally, and related to the process of knowledge acquisition, interviews with experts have also been carried out to acquire the necessary knowledge to create the model.

The following are some of the strengths that are emphasized in the processes involved in this level of maturity:

- There are several lines of work using different AI techniques to have several possibilities in case it is necessary to reject any of them and, in this way, search for the best model that solves the problem.

On the other hand, a set of weaknesses has been detected in this block, which must be addressed to improve the performance of the processes involved. These are:

- Lack of traceability of the defined requirements with the code, deliverables or parts of the generated product.
- No requirements related to project management, data security, traceability, transparency, etc. have been defined.
- There is no follow-up of the comments made at the meetings through the minutes records.

Table 8
Results of the maturity level 2 processes assessment.

Process	Rating
Supply (SUP)	F
Stakeholder Needs and Requirements Definition (SNRD)	P
Life Cycle Model Management (LCMM)	P
Project Assessment and Control (PAC)	L
Quality Assurance (QA)	L
Measurement (MEA)	F
Configuration Management (CM)	P
Knowledge Acquisition (KA)	L

- There is no formal definition of indicators to ensure quality in the different life cycle processes, which can be reviewed, evaluated and managed throughout development.
- It is necessary to utilize specific tools in order to carry out version control on the developed code. This enables specialized functionalities such as commit messages, greater traceability or return to previous versions.
- It is necessary to utilize specialized databases for data management and storage, providing more facilities and functionalities such as version control or greater flexibility and traceability over the data.
- It is necessary to utilize specialized tools for documentation version control.
- There is no appropriate follow-up nor correct traceability of the knowledge extracted from the business and the parts of the final product.

As with the previous maturity level, the identified weaknesses are the result of the development team's lack of experience in the implementation of established software engineering practices. These issues affect the overall efficiency of the process, giving rise to inefficiencies in tracking requirements and maintaining the software quality throughout the development lifecycle. The proposal to address these challenges includes implementing tools and practices for version control, establishing formal requirements, establishing indicators for quality assurance, and providing structured tracking of deliverables (see Table 8).

4.2.3. Maturity level 3: Established

Moving up to maturity level 3, it includes evaluating other processes, such as defining requirements directly related to the system. Functional requirements have a limited definition, i.e., assigning a category for each set of sensor data. Performance requirements are defined in terms of the accuracy of the classification process. Non-functional requirements relate to the size of the provided model to be implemented in the onboard device.

Regarding human resource management in the project, a series of prerequisites necessary for the execution of the project are defined and duly documented, demanding roles such as data scientists or systems engineers. Additionally, collaboration with the stakeholders has been a key factor in the decision-making process at all times. In terms of architecture, no management or definition has been detected in the project. In the testing phase, the employment of validation data facilitated the acquisition of an early evaluation, thereby enabling the refinement of the models towards a higher quality outcome. Meanwhile, subsequent to the establishment of the model, unit tests were conducted on the results thereof. Finally, the customer conducted the system and integration tests; consequently, these were not considered in the evaluation of the processes. The following strengths were identified in this block:

- The people involved in the project and the stakeholders are included in the decision-making.
- The organization counts on specialized profiles in developing AI systems and pivot towards the project's needs.

Table 9
Results of the maturity level 3 processes assessment.

Process	Rating
System Requirements Definition (SRD)	P
Infrastructure Management (IM)	P
Human Resources Management (HRM)	L
Risk Management (RM)	N
Decision Management (DM)	L
Architecture Definition (AD)	N
Integration (INT)	–
Verification (VER)	P
Validation (VAL)	P
Continuous Validation (CV)	F

Table 10
Results of the process attributes assessment.

Process attribute	Rating
PA 1.1 Process Performance	L
PA 2.1 Performance Management	L
PA 2.2 Document Information Management	L
PA 3.1 Process Definition	L
PA 3.2 Process Deployment	P

On the other hand, several weaknesses have been detected. These are:

- No functional requirements have been defined at the beginning of the project, e.g., functional characteristics of the final product.
- The utilization of a project management tool for the consolidation, refinement, analysis and subsequent follow-up of needs and requirements, along with their implementation and validation, has not been observed.
- It is evident that the absence of a formalized risk management framework has resulted in the inability to address significant risks, including the incapacity to resolve issues and risks associated with the technology or methodologies employed.
- There has been no monitoring of possible deviations from the project plan.
- It is evident that there is a lack of knowledge of the architectural characteristics in which the developed model will be deployed, defined and monitored
- It is evident that there is a lack of a formal testing process to validate and verify the accuracy of the data processing process and the operations that preprocess and prepare the data.
- There is no formal verification and validation process.

As with the previous maturity levels, these weaknesses result from inadequate process formalization, lack of specialized tools, and undefined software engineering practices. These gaps increase the likelihood of unmanaged risks and deviations from project goals, compromising the quality and reliability of the final product. The company should implement specialized tools for version control, data management, and documentation to enhance traceability and flexibility to solve these issues. Additionally, they would have to establish formal quality assurance indicators and structured follow-up mechanisms to improve transparency and process efficiency (see Table 9).

4.2.4. Process attributes

In addition to the assessment of each process individually to determine if the scope of the process is satisfied throughout the project, an assessment of the fulfillment of the different process attributes for each process up to capability level 3 according to the MMSIA model was also conducted. The global results obtained in aggregate from all the previous processes are specified in the table below (see Table 10).

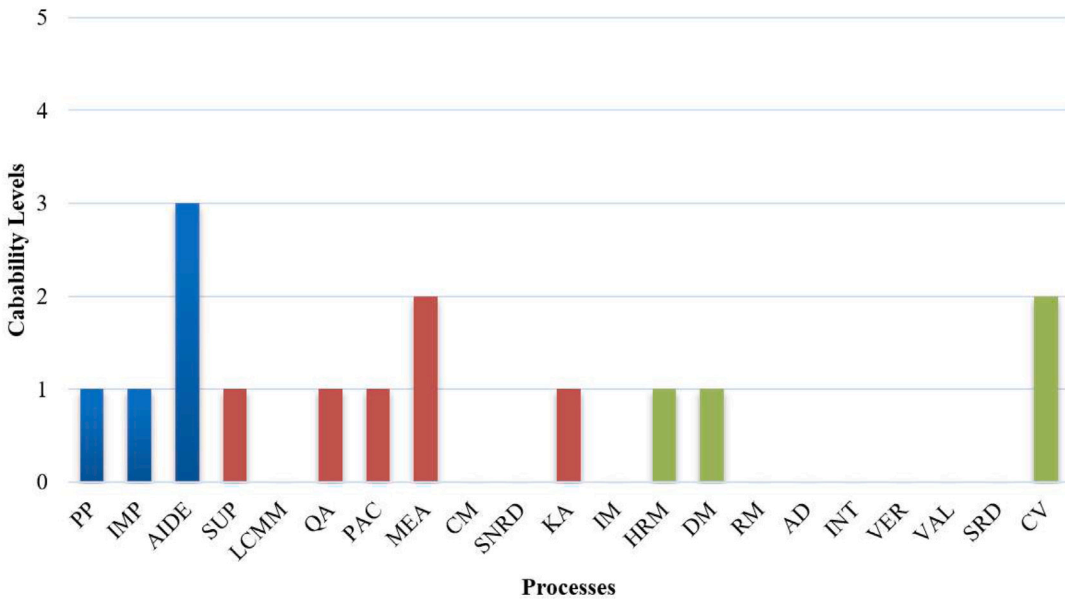

Fig. 3. Capability levels of the assessed processes.

4.3. Evaluation summary

Finally, once the evaluation of the different processes and process attributes involved in the development of the target project were completed, a series of conclusions were extracted, and some opportunities for the improvement of the MMSIA model were detected. Firstly, through the evaluation of the project, a summary of the results that were achieved can be seen in Fig. 3, which shows the capability level of the different processes previously evaluated, grouped in turn by the three maturity levels of the MMSIA model that were included in the scope of the evaluation: blue (maturity level 1), red (maturity level 2) and green (maturity level 3).

In this way, it can be seen how the three processes in maturity level 1 (PP, IMP and AIDE) reach a minimum capability level of 1 as the process performance attribute. However, in maturity levels 2 and 3, there are processes that do not reach a capability level of 1, such as RM or AD, meaning they do not achieve the purpose of the process in the project or, in some cases, they have not even taken the process into account. It is noteworthy to highlight processes such as AIDE that reach capability level 3 due to the complete execution, management and definition of the process in the project. A similar observation can be made in the context of the measurement process, where different measures are taken into account and managed, thus reaching capability level 2. This assessment has enabled the evaluated company to identify the critical points in the development of AI products. Consequently, the identification of improvement opportunities at each stage has facilitated the determination of aspects to be improved in the different processes. This, in turn, has enabled the achievement of a quality and optimal development cycle for AI. This analysis results in the assessed project's maturity level 1 (Basic).

The utilization of the framework has been demonstrated to provide some improvements to AI project processes by providing structure and guidance in key areas such as planning, implementation, and data engineering. For example, following formalized workflows and introducing quality assurance measures enabled more efficient iteration cycles and alignment with international standards. The purpose of the company, after the results of the MMSIA evaluation, is to improve productivity, quality, and development traceability.

On the other hand, regarding the goal of validating the MMSIA model developed in this paper, the evaluation carried out on the project has helped the authors to detect possible points of improvement. One of the main points detected in the model is the lack of a maintenance process, as we have realized how important this process is in AI system development projects due to the addition of specific code templates, data sets, models and documentation that require maintenance and monitoring, which is the cause of the variability of projects with these characteristics. Consequently, the maintenance process will be examined in future works to consider its inclusion in the MMSIA model. Other potential enhancements to the model include the streamlining of activities to enhance its dynamism, or the incorporation of specific exemplars during assessments to facilitate respondent comprehension of the objectives of each process. Notwithstanding the aforementioned recommendations, it is important to acknowledge that respondents expressed satisfaction with the MMSIA model. They highlighted its usefulness, ease of adoption without excessive effort or cost, and its significant value for any organization developing any type of AI system.

5. Conclusions and future work

This paper acknowledges that AI has become an essential tool today, both in the business world and in everyday life. The purpose of AI is to facilitate people's lives and improve efficiency and decision-making in a variety of sectors. Consequently, the development of comprehensive and reliable AI solutions is imperative, with a concomitant necessity to emphasize the quality assurance of the final product throughout the life cycle of such systems, not only directly but also by enhancing the quality of the processes involved in their development, as has been observed in traditional software development.

However, there have been limited advances in evaluating and improving the quality of processes in the development of AI systems. The recent ISO/IEC 5338 standard, which identifies and defines a reference model for AI processes, stands out in this regard. This standard represents a substantial advancement. However, there is still a necessity for frameworks and tools that are specifically designed for its implementation in companies. In this regard, the authors have developed MMSIA, a maturity assessment model aligned to ISO/IEC 33000. The objective of the MMSIA model is to provide companies involved in the development of AI systems with a framework of best practices for the assessment and continuous improvement of the processes employed in the lifecycle of such systems. It should be noted that the MMSIA model developed is agnostic to the tools or technologies used by companies to implement systems and development processes, so it can be adapted or evolved according to the current and future trends or pace of AI growth.

The development of the MMSIA model has been accompanied by a validation process, entailing the evaluation of a real engineering project to check the model's viability and to detect possible points for improvement. The main advantages and disadvantages that have been identified for the model are the following:

- Advantages:
  - The model has been found to be satisfactory for the company under evaluation, with the MMSIA model being perceived as both valuable and profitable for companies developing AI systems.
  - An organizational culture and process structure necessary for the development of AI systems has been established.
  - Increased customer satisfaction and guarantees.
  - Quality improvements for the assessed processes are recommended, resulting in an indirect improvement of the quality of the resulting products.
- Disadvantages:
  - There are limited examples for defining aspects and recommending improvements; the model must be optimized in this respect.
  - The assessment process is complex and extensive. The assessed company suggested streamlining the activities of the model and clarifying some of its aspects.

In light of the identified challenges, a strategy to enhance the MMSIA model has been initiated for future work consideration. It will commence with an exhaustive analysis of the weaknesses found in the model, through the case study developed in this paper, seeking the key points of the assessed processes, as well as the activities and outcomes that are critical to the development of an AI system. Improvements and more detail will be introduced for the most important AI processes, along with new outcomes or activities needed for these processes to help assess their performance. In addition, we will work together with the people involved in the evaluated project in order to carry out continuous monitoring of the processes and to check the progress in their implementation. Following this, the development of a software tool, to support the measurement of process capability, will be initiated. The tool will be able to register the results in a repository of findings detected in the process evaluation, as well as to define, plan and monitor the improvement actions traced to the findings, in order to make the assessment process and continuous improvement more efficient. Finally, parallel to this plan, other case studies will be carried out, evaluating other AI systems development projects and companies with the goal of further improving the MMSIA model. These evaluations are being planned for various areas of AI activity, just as the evaluation of an automotive project that is being carried out in this paper, the model will be used in other sectors such as finance, education and health, with the intention of testing the model and also proving the universal nature of the model defined.

CRediT authorship contribution statement

Rubén Márquez: Visualization, Investigation, Data curation, Writing – original draft, Resources, Formal analysis. **Moisés Rodriguez:** Visualization, Resources, Investigation, Conceptualization, Supervision, Methodology, Formal analysis. **Javier Verdugo:** Writing – review & editing, Resources, Investigation, Supervision, Methodology, Conceptualization. **Francisco P. Romero:** Writing – review & editing, Supervision, Validation, Investigation. **Mario Piattini:** Supervision, Methodology, Formal analysis, Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.engappai.2025.111637.

Data availability

The data that has been used is confidential.

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