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Fuzzy multicriteria evaluation and trends of asset management performance: A case study of Spanish buildings

María Carmen Carnero [a,b,*], Aurora Martínez-Corral [c], Javier Cárcel-Carrasco [c]

[a] University of Castilla-La Mancha, Spain
[b] Universidade de Lisboa, Portugal
[c] Universitat Politècnica de València, Spain

A R T I C L E I N F O

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A B S T R A C T

Asset management has an increasingly important role in organisations, as it can affect productivity and cost effectiveness, the useful life of facilities, the quality of processes, compliance with standards and safety and environmental laws, and more recently, to ensure more sustainable operations and use of resources. However, despite its importance in the provision of services to users, the buildings sector is deficient in contributions in the literature that: a) use an objective multicriteria model, and those developed in a fuzzy environment are even rarer; b) analyse the evolution of asset management in a country over an extended period of time; c) use weightings for each factor analysed, taken from judgements provided by experts in the buildings sector; d) consider all the full data for the sector, rather than average values; e) analyse the buildings complete sector and according to the size of the building. This paper, therefore, sets out a fuzzy multicriteria model for analysing the evolution of the asset management performance of the buildings sector by size (small, medium and large) in Spain from 2000 to 2020. The weightings of criteria and sub-criteria will be calculated based on the judgements of four experts in Spanish maintenance. 229 surveys carried out by the Spanish Maintenance Association are used, looking at all the information provided, rather than average values, developing discrete probability distribution functions to allow the uncertainty of the historical evolution of the asset management of buildings in Spain to be calculated. The average utility variation over the period 2000–2020 in the sector is 1.36 %. This value, although positive, is very low to cover a period of 20 years, and it seems that maintenance departments are not adapted to the new challenges of Industry 4.0.

1. Introduction

Asset management is defined as the coordinated activity of an organisation to realise value from assets. It involves the balancing of costs, opportunities, and risks against the desired performance of assets, to achieve the organisational objectives [1]. Standard ISO 55000:2014 also defines it as the coordinated activity of an organisation to realise value from assets. It thus involves obtaining the expected performance for tangible and intangible assets, through the coordinated efforts of asset managers in managing risk, balancing costs and seeking opportunities to obtain a greater return on assets. This means integrating asset information, to allow informed

* Correspondence to: University of Castilla-La Mancha, Technical School of Industrial Engineering, Avda. Camilo José Cela s/n Ciudad Real, Spain.

E-mail address: carmen.carnero@uclm.es (M.C. Carnero).

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decision making and setting of recommendations at strategic, tactical, and operational levels [2]. However, in the field of buildings, which this study focuses on, maintenance is what allows the building to continue to perform efficiently the functions it was designed for [3]. It should be borne in mind that facilities and their maintenance have significant implications for the quality of service provided, and so, for user satisfaction [4] and asset efficiency.

The importance of asset management and maintenance has changed drastically in recent decades [5], from a necessary evil, a source of costs and with no effect on company profitability, to the modern day, when it has acquired great complexity and a strategic dimension, allowing it to contribute to improving asset reliability, productivity, efficiency and sustainability, and to the availability and quality of products [6], customer satisfaction [7], flexibility and speed of suppliers [8], and the fulfilment of health, safety and environmental requirements or standards [9]. In fact, maintenance is currently critical in achieving total business success [10], although some organisations are still slow to accept these changes [11].

However, approximately 75–80 % of the total costs over the life cycle of a building with 50 years of service are incurred during the operation and maintenance stages, and these costs increase continuously and significantly as a result of inefficient maintenance practices [12]. Furthermore, maintenance and refurbishment decisions are generally taken with insufficient data on the state of the building, which leads to a third of total maintenance costs stemming from unnecessary or inadequate maintenance activities [13]. This is despite being in the middle of the fourth industrial revolution, or Industry 4.0, with the development of the Internet of Things (IoT) and sensors permitting the gathering of information in real time to manage the operations to be carried out. The static and dynamic information about the asset can thus be combined, which would significantly assist the decision-making process [14]. However, as Apostolidis [15] describes, maintenance is always in crisis; In times of economic growth, maintenance departments do not have enough time to carry out the work; activities are always carried out urgently. Further common problems are lack of maintenance experts (managers, supervisors and technicians), insufficient budgets, understaffed departments without economic resources for training and, during periods of recession, maintenance suffers funding reductions that lead to personnel reduction, very limited budgets, and elimination of any type of investment.

To achieve real change in the asset management paradigm, effective maintenance performance is necessary, and in order to control this achievement, it is essential to identify and determine the most important maintenance indicators, in order to subsequently assess them and compute the maintenance function performance achieved [10,16]. The literature proposes different approaches to measure maintenance performance [17–19]:

1. The Balanced Scorecard (BSC). Originally developed by Kaplan and Norton [20], it was later adapted for application to the maintenance area by Tsang et al. [21]. The BSC allows the maintenance strategy to be associated with the overall business strategy. The BSC integrates financial and non-financial measures for maintenance performance using the perspectives related to: financial, customers, internal processes and learning and growth. For each of these perspectives, the goals to be achieved, indicators to measure the level of performance achieved in each objective, the goals that quantitatively represent the degree to which the objectives are achieved and the actions to be applied to obtain the desired results, must all be defined. The indicators are defined for the various hierarchical levels of the organisational structure, with different purposes according to each user. Users at the highest hierarchical level are concerned with overall administrative performance, while those at functional or lower levels are concerned with the physical condition of assets. If a corporate indicator shows a problem, lower level indicators should define and clarify the cause of the problem.
2. The system audit approach proposed by Dwight [22]. This approach consists of a system audit to measure the extent to which the performance of the maintenance area contributes to the organisational success, or is aligned with the organisation's objectives. To do this, the value-based performance measurement takes into account the impact of maintenance activities on the future value of the organisation. Value is defined as the probable future earnings of a system. This system classifies the performance measures into a hierarchy according to their implication in the impact of the maintenance area on the business. This hierarchy is made up of five levels, called: visible bottom-line impact, profit-loss and overt cost impact performance, instantaneous effectiveness measures, system audit approach and time-related performance measurement. Its contribution is fundamentally related to the gap between an action and its result.
3. The Alsyouf model (the extended BSC). This model developed by Alsyouf [23] considers the extended value chain (including suppliers, employees and other stakeholders). It includes performance measures using the perspectives: corporate business (financial), society, consumer, production, support, functions, human resources and supplier perspectives. The extended BSC model is structured into three parts:

- Part 1: The downstream organisation elements that include corporate business, society and consumer. The strategic objectives of the organisation should be in line with the vision and strategy of the organisation.
- Part 2: The operations processes include two perspectives: the production and the support activities perspective (which includes maintenance, quality and logistics).
- Part 3: The upstream organisation elements include the human resources and suppliers and consultants perspectives.

The extended BSC changed the consideration of the maintenance function from the classic cost centre to the current profit generating function.

4. The Maintenance Scorecard (MSC). Proposed by Mather [24], it provides a framework so that the maintenance function can act as a source of competitive advantage using indicators that guide the development and implementation of the strategy. The MSC divides

the organisation into three hierarchical levels: corporate, strategic and functional. At the corporate level, competitive advantages are related to a set of skills, competencies and capabilities that allow the organisation to compete in target markets. At the strategic level, strategic advantages are found as a unique set of skills, competencies and capabilities that allow the organisation to obtain competitive advantages. At the functional level, strategic assets are included, considered as a set of skills, competencies and capabilities that are necessary to obtain strategic advantages. Once the strategic requirements of each hierarchical level have been established, the MSC defines performance indicators to achieve the requirements based on the perspectives of productivity, learning, quality, environmental, safety and cost effectiveness.

5. The model proposed by Al-Najjar [25]. This model describes and quantifies the impact of maintenance on business's key competitive objectives related to production, quality and cost. To do this, it divides business activities into two categories to be carried out at the operational and strategic levels. Savings obtained by applying more efficient maintenance and that have the greatest impact on the organisation, for example, fewer failures per year, or shorter average stoppage time, can be quantified over a period of time. However, some improvements that are not easily quantifiable without special research are not included (for example customer satisfaction). The model includes the interactions between maintenance and competitive advantage, and the role of maintenance in creating and improving business competitiveness based on internal resources. This model can be used to evaluate the cost effectiveness of maintenance investments and serve as support in making strategic decisions about the choice of improvement plans.
6. The system of indicators of the Society for Maintenance & Reliability Professionals (SMRP). SMRP is a nonprofit professional society that developed a system consisting of 67 indicators (updated to 70 metrics), organised into the following five pillars of the maintenance and reliability body of knowledge [26].

- Business and management. Describes the skills to be used to translate the organisation's business goals into appropriate maintenance and reliability objectives that support and contribute to the organisation's business results. Therefore, this pillar allows the maintenance and reliability program to be aligned with the business goals.
- Manufacturing process reliability. Relates maintenance and reliability activities to the manufacturing process to ensure that maintenance and reliability activities improve the manufacturing process. This pillar makes it possible to minimise variation in processes so that products meet quality specifications. It includes six indicators, among which, for example, is Overall Equipment Effectiveness (OEE).
- Equipment reliability. Includes activities used to evaluate the current capabilities of equipment and processes in terms of reliability, maintainability, availability, and criticality. It also includes activities aimed at selecting and applying the most appropriate maintenance practices so that equipment and processes continue to provide their intended capabilities in the safest and most cost-effective manner. This pillar facilitates the selection and application of the correct maintenance strategies and activities so that the level of reliability associated with the equipment is maintained. It includes nine indicators, including, for example, Mean Time Between Failures (MTBF), Mean Time to Repair or Replace (MTTR), Mean Time Between Maintenance (MTBM), Mean Downtime or Mean Time to Failure (MTTF).
- Organisation and leadership. Describes processes to ensure that maintenance and reliability staff are the most qualified and best assigned to achieve organisational maintenance and reliability goals. This pillar ensures that adequate resources are available with appropriate training in addition to managing the change that will take place in the organisation. It includes four indicators such as maintenance training cost and maintenance training hours.
- Work management. Focuses on the skills used to perform maintenance and reliability work. It includes scheduling and planning activities, quality assurance of maintenance activities, warehouses and inventory management. This fifth pillar aims to ensure that maintenance activities are carried out as planned and the correct responses are available to ensure the level of work. It includes 44 indicators.

The pillars to be used and their order will depend on the state of the organisation.

7. The system of indicators of the European Federation of National Maintenance Societies (EFNMS). In 2000, EFNMS defined a set of maintenance Key Performance Indicators (KPI) to measure maintenance performance that were incorporated into the European standard EN 15341:2007 Maintenance Key Performance Indicators. The current standard EN 15341:2023 [27] uses seven areas to assess maintenance: health, safety and environment in maintenance, maintenance management, maintenance staff competence, maintenance engineering, organisation and support for maintenance, and administration and supply. The standard includes 71 indicators grouped into: economic, technical and organisational aspects. The indicators are distributed in three levels similar to the hierarchical levels of an organisation. At Level 1, 19 indicators are included, 6 of them economic, 5 technical and 8 organisational. Level 2 has 12 indicators, 8 being economic, 2 technical and 2 are organisational, and Level 3 includes 40 indicators, 10 of which are economic, 14 technical and 16 organisational. These KPIs can be used [27]:

- Periodically, for the preparation and monitoring of budgets, comparing the results with the expected, planned or real values.
- Specifically, within audits, benchmarking studies or other specific comparative evaluations.

Since 2006 EFNMS and SMRP have been developing a harmonisation process to obtain standard indicators for maintenance and reliability performance, in this way an organisation can compare maintenance performance internally or externally using predefined global maintenance and reliability indicators. Harmonised indicators provide a common platform for global organisations to compare their facilities across borders. An indicator is considered common if, according to the EFNMS and SMRP definitions, it has the same basic equation or can be universally applied [18]. In the first harmonisation, carried out in 2007, sixteen metrics were harmonised and nine additional indicators were identified for harmonisation. In 2010, 29 indicators were harmonized, and currently the EFNMS have managed to compare and explain 40 indicators from the standard EN 15341:2019 and 36 metrics from the SMRP system [28]. For the harmonised indicators there is a guideline describing:

- The definition of the indicator.
- The objective, that is, the performance to be measured.
- The equation to be used.
- The definition of the components.
- An example of indicator calculation.

In addition, in 2015, UNE-ISO 55001:2015 standard on asset management was published, which provides the framework with guidelines to ensure compliance, although it is the organisation that has to establish the best way to achieve it. The prior standard, together with the UNE-EN 16646:2015 standard, have made the operation and maintenance of buildings importance and visibility. Furthermore, the EN-17007:2017 standard formalises the maintenance service by breaking it down into processes which, among other advantages, facilitate internal and external benchmarking of companies and organisations [29]. To the above must be added ISO 41001:2018 on facilities management [30] that solves various problems by facilitating quality control of maintenance services and proposing a conceptual framework for the best maintenance practices, using the concept of continuous improvement through the Plan-Do-Check-Act (PDCA) cycle [31]. More recently, BS 8210:2020 (Guide to Facilities Maintenance Management) applicable to most types of facilities, assists decision-making on the implementation of maintenance strategies and policies, and the impact of maintenance approaches on the objectives of the organisation [32]. However, like ISO 55001, it does not provide specific procedures on how to develop maintenance management [33].

Since maintenance assessment depends on a number of factors or criteria, both quantitative and qualitative [34], the application of MultiCriteria Decision-Making (MCDM) methods is highly appropriate ([10,35]). In addition, these methods allow a weight to be assigned to each evaluated criterion or KPI, particularised for each company, industrial sector or country with conflicting criteria. Thus, the literature shows few contributions, among which Van Horenbeek and Pintelon [35] stand out. They developed a maintenance performance measurement framework which aligns the maintenance objectives at all management levels with the maintenance performance indicators used for this purpose, Analytic Network Process (ANP). The methodology is tested in companies in different types of industry. Gonçalves et al. [36] develop a methodology for the selection of maintenance KPIs using ELECTRE I. Darestania et al. [37] used a combination of fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) and ANP method analysis to measure maintenance performance and determining the causal relationships between the criteria and sub-criteria in an automotive industry. Gandhare and Akarte [38] developed a framework using 20 maintenance practices as criteria in an AHP model for evaluating and benchmarking maintenance performance in the select agro-based industry which included sugar, textile and dairy industry; the model used specific judgements of the agro-based industry executives. In the same environment of agro-industries, Soltanali et al. [39] defined critical success factors categorised into organisation management, human-related and organisational aspects of a maintenance management system to evaluate the operational performance using a combination of the Best-Worst Method (BWM) and DEMATEL.

Research on maintenance performance is even rarer when considering the use of MCDM techniques in a fuzzy environment. Among them, only the research of Carnero [40] has been found, which used fuzzy AHP to apply maintenance benchmarking in small Spanish companies. Stefanovic et al. [41] developed a model combining fuzzy sets and genetic algorithms to classify and optimise maintenance performance indicators in small and medium enterprises. Ghazali et al. [42] initially identified 106 factors, to later focus on 18 performance improvement actions that were finally prioritised using the fuzzy Delphi method; All this is applied to the analysis of changes in maintenance management of a lube-blending plant in Malaysia. Amrina et al. [43] described a multicriteria approach based on fuzzy ANP with 16 KPIs categorised into economic, social and environmental aspects, to assess sustainable maintenance performance in the cement sector industry. Yilmaz et al. [10] used the fuzzy DEMATEL method to define the most important factors by analysing and ranking the cause-effect relationships to improve overall maintenance performance of a company. The following six strategic aspects were taken into account: financial, technical, internal process, support, human resources and health, safety, and environment.

Nonetheless, in the specific application of performance evaluation or benchmarking in buildings, the literature only contains the precedents of Carnero [44] who used fuzzy AHP to apply competitive and generic benchmarking in Spanish Buildings. However, the Chang extent analysis method was used, which has a number of theoretical problems and only in large buildings. Using similar criteria, Karimi et al. [45] used the fuzzy BWM for the maintenance assessment of hospitals in a city in Iran. Dejaco et al. [13] developed a set of KPIs to periodically monitor the condition of buildings throughout their life cycle. AHP was used to assign an importance to each indicator. In addition, the proposed KPIs can be connected with other economic indicators, which allow the calculation of restoration, planned maintenance and reconditioning costs, and are also a source for the application of the benchmarking process.

Therefore, despite the importance attached to asset management, the number of studies that apply MCDM methods in buildings maintenance and facilities management maintenance performance is still very limited [46,47], and the existing ones are related to the selection of the maintenance strategy [46,48], or the definition of maintenance inspection policy [49]. However, MCDM methods have been widely used in other sectors, such as manufacturing companies or chemical and petrochemical plants.

It should be noted that the literature in general and the EN 15341 standard consider the KPIs to be equally important and, furthermore, in benchmarking studies, average reference values of each KPI relative to each industrial sector are used to compare them with those of a company. However, in asset management or maintenance this type of comparison is not very useful [50] since, although the use of ratios to quantify performance provides a set of measures to be used in benchmarking, it does not provide appropriate standards of performance, since they are not supported by established goals [22].

However, despite its importance in the provision of services for users, the buildings or infrastructure sector only accounts for 6 % of the research papers in the literature related to maintenance optimisation [6] or that allow the development of sustainable and effective maintenance practices [12]. Much previous research focuses on maintenance according to building typology, leaving deficiencies in systematic approaches for the application of efficient maintenance practices based on objective and realistic methods and procedures. In addition, in particular, the literature does not show precedents that use fuzzy MCDM to evaluate the evolution of maintenance performance in the building sector in a country over a long period, since the few previous studies focus on a specific instant to the sector, company or country.

To appropriately address some of the limitations of the literature mentioned above, the main theoretical and practical contributions of the proposed research are the following:

- To expand the contributions of fuzzy MCDM models in maintenance performance in the buildings sector to incorporate the uncertainty, ambiguity or imprecisions implicit in human judgements in decision making.
- To apply an objective and realistic model to understand the evolution of building maintenance in Spain over a 20-year time period, from 2000 to 2020.
- To analyse the behaviour of the buildings sector in general, although it will be particularised according to the size of the company (or building), rather than only for a specific type of buildings such as hospitals or educational centers.
- To incorporate into the model all the information available from the buildings sector in each year analysed, and not only average values. In this way, more precise results for maintenance performance status are obtained.
- To obtain its own weighting for each criterion analysed according to its importance for the sector. These weightings will be provided by experts in Spanish Building maintenance.
- To use the surveys carried out at a national level by the Spanish Maintenance Association, thereby guaranteeing the reliability of the data used, and greater a greater quantity of data than most of the studies used in the literature.
- Rather than the Chang extent analysis method, the geometric mean method suggested by Buckley [51] will be used because it is easier to apply and understand than other methodologies, and it guarantees the existence of a unique solution of the reciprocal comparison matrix.

Therefore, this research proposes a fuzzy MCDM model constructed by means of integration of fuzzy AHP, multi-attribute utility and Monte Carlo simulation in which a discrete probability distribution function is incorporated into each criterion according to the behaviour of the buildings sector over twenty years, from 2000 to 2020. The choice of fuzzy AHP rather than other multicriteria techniques is justified in Section 4 Research Methodology. The criteria and sub-criteria used have a specific weighting according to their importance to asset maintenance in the Spanish building sector provided by four experts in buildings maintenance. In addition, the complete information of the sector is used each year evaluated instead of average values, which allows obtaining a more precise value that includes a measure of uncertainty, computed from Monte Carlo simulation. The model allows the evolution of level of excellence applied in asset management in the Spanish buildings sector, to be quantified, analysed in general, and by different building sizes:

- Small: up to 200 workers.
- Medium: from 201 to 500 workers, and
- Large: over 500 workers.

This paper is structured as follows. Section 2 brings together the literature about the state of maintenance in different countries, and specifically in the building sector. Section 3 describes the fuzzy AHP method. Section 4 describes the research methodology applied in this research. Section 5 sets out the fuzzy multicriteria model to evaluate maintenance performance in Spanish buildings. Section 6 shows the results of the application of the model and the trends detected for the next five years, and the sensitivity analysis. Finally, Section 7 presents the conclusions.

2. Literature review

Among the studies that evaluate the level of excellence or the existing deficiencies in the field of asset management or maintenance by country, Ikhwan and Burney [52] should be highlighted. This is among the first contributions to detect deficiencies in Saudi Arabia: deficiencies in the application of scientific principles applied to actual maintenance management, optimisation of the supply of spare parts, introduction of computerised maintenance management systems and improvement of task control using work orders and report generation. Subsequently, Assaf et al. [53] used three indicators and Data Envelopment Analysis (DEA) to assess the efficiency of maintenance departments in the petrochemical industry in Saudi Arabia. Other investigations in Asia have been carried out by Tse [54] who surveyed 21 Hong Kong businesses, noting that the most commonly applied maintenance policies are corrective and preventive maintenance, deficiencies in the use of other more advanced practices and that the investment in maintenance is much lower than that of the company's assets and profits. Ahuja and Khamba [55] analysed the barriers and success factors of the Indian manufacturing business in implementing Total Productive Maintenance (TPM), because this policy can contribute substantially to organisational performance improvements. The results show that implementing TPM leads to organisational, cultural, behavioral, technological, operational, financial, and departmental problems, demonstrating the need to establish collaboration between the Maintenance Department and other improvement initiatives in the organisation. On a similar theme, Modgil and Sharma [56] analyse the impact of TPM and Total Quality Management (TQM) practices on operational performance on Indian pharmaceutical plants. As a result, they saw how TPM practices have a significant impact at the operational level, reduction of quality costs, R&D, product innovation and technology management. Gandhare et al. [38] researched maintenance management performance practices in the sugar industry in India, observing that the level of maintenance performance depends on whether the organisation is private or cooperative. Wijesinghe and Mallawarachchi [57] assessed 15 indicators by assigning weights to each indicator to assess the garment industry in Sri Lanka. Their results show that the current importance of maintenance is not considered, as well as the need to apply a performance-based approach in maintenance management. Nisa et al. [58] carried out a maintenance practice survey in Indonesian wood and furniture industries, giving as a result that on average, the majority applied suitable maintenance practices and have excellent performance management, as well as being fully aware of the importance of maintenance in success. business. Following the same methodology Gandhi et al. [59] analyse the maintenance management in micro, small and medium Indonesian food snack companies, showing that planning and control, financial aspects and maintenance costs show a strong correlation with continuous improvement. Olanrewaju et al. [4] recognise that buildings are not well maintained in Malaysia and note that public hospitals have a greater dedication to maintenance, although private ones spend five times more on maintenance than public ones. In addition, public hospitals outsource many of the activities because the managers consider that building maintenance is not a key service. That is, maintenance management departments should be assigned strategic functions, but while private hospitals recognise the application of these functions through an increase in expenses, the maintenance services provided are not well executed by the departments themselves. In fact, maintenance departments focus on carrying out small repairs, there being no correlation between the maintenance organisation and the age and size of the building and, furthermore, maintenance managers do not have academic training suitable for this role.

At the European level, Jonsson [60] and Alsyouf [61] surveyed the state of maintenance management in Swedish business, observing the limited importance given to maintenance, which is seen as a source of expense, and a third of maintenance time is spent on unplanned activities. There are also deficiencies in the application of Reliability Centred Maintenance (RCM) and TPM, and inefficiencies in maintenance planning and scheduling, which makes it difficult to achieve the established objectives and thus obtain a competitive advantage. Luxhøj et al. [62], in their survey of businesses in Denmark, Finland, Norway, and Sweden, showed a lack of resources in maintenance, with a tendency to carry out activities in the short term instead of developing a strategic plan that includes long-term planning. There was also a lack of integration between the organisational strategy and production area and the maintenance function. On the other hand, the research carried out by Holgeid et al. [63], exclusively in Norwegian businesses, quantify in 62.3 % the application of functional maintenance and 37.7 % in the development of new systems and functional perfective maintenance. Cholasuke et al. [64] surveyed 18 manufacturing companies to look at the status of maintenance management in the UK, showing that only a third of organisations apply good maintenance management practices and are aware of the full benefits that can be obtained from their application, and actually realise the full benefits. In Belgian and German companies, it can be seen that the established competitive priorities determine the application of different maintenance strategies and, as they become more competitive, they apply a higher percentage of preventive and predictive maintenance, better planning and control systems, and the organisational structure of maintenance are more decentralised [65]. Also in Belgian industries, Muchiri et al. [66] analysed the application of KPIs noting that the most frequently used are those related to equipment, maintenance costs and safety. In addition, divergences were detected between the maintenance objectives of the organisations and the KPIs used, being therefore used in very limited cases for decision making. In Italy, Chinese and Ghirardo [67] carried out a survey among 100 small sized manufacturing business firms. They observed that the size of the company, as well as aspects related to planning and control, did not seem to affect maintenance performance. However, the increase in the use of preventive maintenance and, above all, predictive maintenance, effectively improves maintenance performance. Branská et al. [68] described the status of maintenance systems based on the evaluation of strategic and tactical operational planning, implementation and control in Czech chemical and food companies. The areas for improvement are focused on the implementation of strategic objectives, the system of indicators to quantify maintenance performance and the implementation of information systems, the integration of maintenance planning with supplier and customer systems, as well as the use of mathematical methods to optimise business performance. In the case of Spain, the Spanish Maintenance Association (SMA) carries out sectoral surveys every five years and, in the specific case of the buildings sector, Porras [69] carried out a benchmarking study in 35 buildings during 2001 and 2002. However, these surveys, which could be used with continuous improvement objectives are barely used in Spanish organisations [70], although they have been widely used in companies in Canada, the United States, and New Zealand.

The research of Connaughton [71] in US companies showed that there was no correlation between the structure of the organisation and the use of advanced maintenance methods. It also detected the extensive application of condition monitoring techniques (vibration analysis, lubricants, etc.) compared to other more labour intensive methods (eg RCM); he also detected deficiencies in the planning and scheduling of maintenance. Also related to the application of RCM [72], states that only 18.30 % of the 601 respondents completed a project to implement this policy and obtained the expected results. For his part, Wireman [73,74] shows in detail the evolution of the level of excellence in maintenance in the USA, providing benchmarks of low and high ranges and best practice in the areas: work order coverage, productivity rates, maintenance cost, preventive maintenance compliance, maintenance labour cost, stores investment, etc. Jin et al. [75] also surveyed areas in manufacturing industry related to: a) performance metrics for productivity, intelligent maintenance, and product quality; b) maintenance strategy and effectiveness; c) key factors that affect maintenance performance; d) common problems, failure modes, and bottlenecks for manufacturing processes and equipment; e) future trends for prognostic and health management technology for smart manufacturing from an industrial perspective. They found that maintenance effectiveness, maintenance strategy, and human resources allocation for maintenance were strongly correlated with the size of the organisation. However,

Table 1
Literature review related to the application of MCDM methods in maintenance performance.

Reference	Year	Methods/techniques applied	Application	Principal contribution	Country of application
Parida and Chattopadhyay (2007) [88]	2007	Multicriteria hierarchical framework	-	A general multicriteria hierarchical framework for maintenance performance measurement applicable to a wide range of industries	-
Parida (2007) [89]	2007	Multicriteria hierarchical framework	Pelletisation plant	Identifying the relevant maintenance indicators and adapt a balanced, holistic and integrated multicriteria performance management model for a plant and to align the plant performance with the corporate strategy	Sweden
Carnero (2014)	2014	AHP and fuzzy AHP	Big buildings	A decision support system for applying competitive and generic benchmarking in big buildings	Spain
Van Horenbeek and Pintelon (2014)	2014	ANP	Manufacturer of wind turbine components, manufacturer of industrial systems and provider of additional service contract, medium size hospital, large university hospital, military aircraft operator	Definition of a framework for maintenance performance measurement on levels: strategic, tactical and operational	Belgium
Carnero (2014)	2014	Fuzzy AHP	Small companies	Model to compares the state of maintenance of a company both globally and by criteria, with companies in its own sector and in other sectors which show better results	Spain
Gonçalves et al. (2015)	2015	ELECTRE I	-	New approach to selecting relevant maintenance KPIs	-
Stefanovic et al. (2015)	2015	Fuzzy Ordered Weighted Averaging Operator (FOWA) and genetic algorithm	Metal processing small and medium enterprises	Approach to ranking and assessment of maintenance performance KPIs, and to get an overall ranking of maintenance performances	Serbia
Dejaco et al. (2017)	2017	AHP	Construction industry	Providing KPIs able to help make the best decisions when acquiring, operating, maintaining and repairing a building. Using these KPIs in a building condition assessment procedure	Italy
Ghazali et al. (2019)	2019	Fuzzy Delphi	Lube blending plant	Studying the contribution of selected maintenance department stakeholders from within the plant to develop tailor-made intervention strategies for maintenance performance improvement	Malaysia
Darestania et al. (2020)	2020	Fuzzy DEMATEL and ANP	Automotive industry	Determining the relationships between some case-dependent selective criteria and sub-criteria, and their relative importance	Iran
Karimi et al. (2020)	2020	Fuzzy Best-Worst Method	Hospitals	Maintenance evaluation of hospitals	Iran
Amrina et al. (2020)	2020	Fuzzy ANP and Interpretive Structural Modelling method	Cement industry	Selection of KPIs for sustainable maintenance performance evaluation and to determine the relationship amongst the KPIs and its importance	Indonesia
Gandhare and Akarte (2022)	2022	AHP	Sugar, textile and dairy industry	Framework for evaluating and benchmarking maintenance performance within the agro-based industry and between agro-based industries	India
James et al. (2023) [90]	2023	AHP	Automobile Garages	A framework for the assessment and comparison of sustainable maintenance performance of automobile garages	India
Yilmaz et al. (2023)	2023	Fuzzy DEMATEL	Chemical industry	To define the most important indicator for chemical industry maintenance	Morocco
Soltanali et al. (2023)	2023	Best-Worst Method and DEMATEL	Agro-industries	Identifying critical success factors and major criteria influencing effective maintenance management in agro-industries	Iran

there was a clear difference in strategy and maintenance technology in large and small and medium-sized companies. In contrast, the average values of task planning and scheduling and TPM levels are similar in large and small and medium-sized companies. Also, small and medium-sized companies are less willing to reform their maintenance departments as they experience more barriers to changes in the organisational structure, less willingness to innovate, and limited human and financial resources to carry them out. In the case of the assembly plant industry in Mexico, Dowlatshahi [76] states that preventive and predictive maintenance are not applied in most of the companies surveyed, there is only classical corrective maintenance. In medium-sized and large Brazilian companies, Bittencourt et al. [77] found the need to reduce corrective maintenance and, therefore, to increase planned maintenance. In addition, organisations that apply RCM and a higher percentage of predictive maintenance to the detriment of corrective maintenance tend to consider maintenance as a source of competitive advantage.

Muchiri et al. [78] defined a global assessment index with which to characterise the excellence of maintenance practices developed in Kenyan organisations; The results show that maintenance is partially planned and performance depends on the competence and experience of the workers. Naji et al. [79] analysed the maintenance management status of Moroccan industries for which seven companies were studied qualitatively and thirty-one companies quantitatively. They found that most of the companies surveyed did not have a general maintenance model, basing most decisions on random factors instead of data analysis.

Finally, Le et al. [33] propose a set of improvement actions for the maintenance management of public schools in New Zealand, including: improving communication between the personnel involved, improving training programs, establishing a system for assessing the maintenance performance and a centralised information system with a feedback loop. This would make it easy to establish what schools need and to update the building maintenance management system in line with a long-term strategy.

In the field of the buildings sector, the literature focuses on specific types of buildings, especially healthcare facilities, because they undergo a much higher wear and tear than others due to the continuous use of the facilities 24 h a day, 365 days a year [80]. Better access to health services and, in higher income countries, the rapid aging of the population, leads to an increase in the use of health services [81,82] as well as a demand for higher quality care [4]. In addition, there is an increase in the number of services provided annually due to the appearance of new diagnostic, treatment and rehabilitation techniques, and the aging of the population in developed countries [83]. At the same time, hospital maintenance departments are experiencing a reduction in funds that can be quantified as 15.37 % in the last 14 years in Malaysia [4]. All of the above causes well-worn facilities and medical equipment, and sensors drift out of calibration [84].

In addition, universities and health care organisations are experiencing an increase in deferred maintenance, consisting of postponing building and equipment maintenance activities to save costs or meet budget targets [85]. These types of buildings, which are part of public buildings, are not adequately maintained, especially in most developing countries [86], which causes waste and reduced life cycle. However, other private buildings have similar maintenance management problems [87]. In most public buildings corrective and preventive maintenance activities are carried out based on the condition of the building based on the results of an inspection. However, what really matters are the functions that the building performs and not its condition, that is, it is the needs of the building's users that should determine the management maintenance policy, purposes and objectives [87]. Another factor recognised is the increase in outsourcing of maintenance in public and private buildings [3,4,33,34]. In many cases, since the directors of the organisations manage them on behalf of another party (local, regional or national administrations) but do not have knowledge about maintenance management, they frequently delegate it to third parties [33].

Table 1 shows the literature that applies MCDM methods to maintenance performance. It shows that all contributions since 2015 are applied in specific sectors, types of industry or buildings. Therefore, there is a need to define and develop specific KPIs for different sectors and applications, rather than general indicators. This is in line with the conclusions of Van Horenbeek and Pintelon [35], that each business sector has its specific maintenance objectives on different organisational levels which defines their maintenance strategy. Although specific maintenance performance indicators have been produced for some sectors, many of them exist without research in the literature. Of the 16 studies included in the table (the first two do not use a technical MCDM as such, although they are the first to consider a hierarchical approach and assign different weights to each criterion), the most used MCDM method is AHP or fuzzy AHP at 31.25 %, followed by DEMATEL and ANP with 18.75 % each. 56.25 % of the investigations use a fuzzy approach, recognising its advantages in the giving of judgements by experts in the field of maintenance. Furthermore, a need has been identified to promote the use of more practical applications in maintenance, and the challenge for organisations to start applying the concept of sustainable maintenance, defined as a process of continuous development and constant improvement of maintenance processes, increasing efficiency (operational excellence), safety of operations and maintenance of technical objects and installations, and focused on employees [43].

Therefore, as a conclusion, the literature shows concern for the need to optimise the maintenance process, although the reduction of maintenance costs does not allow these improvements to be transferred to the efficiency or productivity of organisations. In addition, the studies carried out refer to a specific moment in time, and, although there are some studies by different authors in the same country, the indicators used are not similar, so it is not possible to compare the development of asset maintenance over time. In addition, the use of objective models such as MCDM to evaluate asset management performance is very limited, and even more so when applied to the buildings sector, in contrast to the significant amount of this type of model applied to other types of organisation, primarily manufacturing.

3. Fuzzy analytic hierarchy process

In the real world, decision makers prefer to use linguistic judgements rather than deterministic values, due to the inherent complexity of providing exact data when trying to compare criteria or alternatives [91]. Fuzzy triangular numbers allow doubtful, vague, imprecise, ambiguous or uncertain information that characterise decisional problems [92] to be included in the decision-making process [93]. Subsequently, these linguistic terms can be associated to fuzzy number [94], thus improving the decision-making process [95].

A triangular fuzzy number is made up of three elements $\widetilde{d} = (l, m, u)$ where l is the lower bound, m the greatest possible value, and u the upper bound, satisfying $l \leq m \leq u$ [96]. $\widetilde{d}$ is defined by a continuous membership function that assigns to each element x a real number in the interval [0,1] as shown in Eq. (1) [97].

$$\mu_{\widetilde{d}}(x) = \begin{cases} (x-l)/(m-l), & \text{if} \quad l \leq x \leq m \\ (u-x)/(u-m), & \text{if} \quad m \leq x \leq u \\ 0, \text{otherwise} & \end{cases} \tag{1}$$

Fuzzy logic combined with AHP has been widely applied in the literature in recent years, and is the second most applied MCDM technique, after AHP [98]. The literature includes different fuzzy AHP methodologies for computing criteria weights; The first methodology based on logarithmic least squares was from van Laarhoven and Pedrycz [99]. This was followed by Buckley's [50] proposal for geometric means, the modification of the proposal by van Laarhoven and Pedrycz due to Boender et al. [100], Chang's synthetic extent analysis [97], Xu's fuzzy least-squares priority [101], the lambda-max method of Csutora and Buckley [102], fuzzy preference programming by Mikhailov [103], and two-stage logarithmic goal programming from Wang et al. [104]. Although the Chang extent analysis methodology is the most commonly applied in the literature, many theoretical problems with its use have also been described, such as that the weights obtained do not represent the relative importance of the criteria or the alternatives, which can generate problems of low robustness, unreasonable priorities and loss of information [98]. It can also produce less accurate results [105]. Therefore, this study applies the methodology suggested by Buckley [51], since it is easier to apply and understand than other methodologies, it guarantees the existence of a single solution of the reciprocal comparison matrix [106] and has not received much criticism, unlike other methodologies [107].

The procedure for applying Buckley's geometric mean method is described below [94,108,109]:

Step 1. Analyse the problem. The problem, constraints, boundary conditions must be clearly defined, and all possible solutions or alternatives to be evaluated, stakeholders and scenarios must be identified.

Step 2. Select the expert or group of experts. A decision maker or a group of decision makers, experts in the problem to be analysed must provide the judgements related to the pairwise criteria comparison that best reflect the relative importance between two criteria.

Step 3. Select the fuzzy scale. The literature contains different fuzzy scales. However, this research uses that proposed by Lamata [110], which is shown in Table 2, where A_i and A_j with options or alternatives to compare. It is a scale very similar to the one proposed by Saaty, but in a fuzzy setting, and is widely used in the literature (for example, [94,108,109,111]).

Step 4. Structure the problem. The problem must be structured at different levels to build a hierarchy, placing the goal at the top of the hierarchy, then the criteria and sub-criteria, and the alternatives at the bottom.

Step 5. Find the fuzzy pairwise matrices among the hierarchy. The decision makers must provide the fuzzy judgements when pairwise comparing criteria, sub-criteria or alternatives. To do this, a fuzzy scale is used, as defined in Step 3. The scale of qualitative assessments is converted into fuzzy numbers according to the equivalences in Table 1, to build the fuzzy pairwise comparison matrix $\widetilde{A}^k$, at the same level of hierarchy. $\widetilde{A}^k$ is defined as a fuzzified reciprocal n-by-n matrix associated with the decision maker k, where $\widetilde{d}_{ij}^k$ is the judgement issued on the preference of the ith element over the jth element using a triangular fuzzy number $\widetilde{d}_{ij}^k \forall i,j \in \{1, 2, \ldots, n\}$.

$$\widetilde{A}^k = (\widetilde{d}_{ij}^k)_{nxn} = \begin{pmatrix} \widetilde{1} & \widetilde{d}_{12}^k & \cdots & \widetilde{d}_{1n}^k \\ \widetilde{d}_{21}^k & \widetilde{1} & \cdots & \widetilde{d}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{d}_{n1}^k & \widetilde{d}_{n2}^k & \cdots & \widetilde{1} \end{pmatrix} \tag{2}$$

Table 2
Triangular fuzzy scale of preferences.

Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
A_i and A_j are equally important	$\widetilde{1} = (1,1,1)$	(1, 1, 1)
A_i is between equal and moderately more important than A_j	$\widetilde{2} = (1,2,3)$	(1/3, 1/2, 1)
A_i is moderately more important than A_j	$\widetilde{3} = (2,3,4)$	(1/4, 1/3, 1/2)
A_i is between moderately and strongly more important than A_j	$\widetilde{4} = (3,4,5)$	(1/5, 1/4, 1/3)
A_i is strongly more important than A_j	$\widetilde{5} = (4,5,6)$	(1/6, 1/5, 1/4)
A_i is between strongly and very strongly more important than A_j	$\widetilde{6} = (5,6,7)$	(1/7, 1/6, 1/5)
A_i is very strongly more important than A_j	$\widetilde{7} = (6,7,8)$	(1/8, 1/7, 1/6)
A_i is between very and extremely strongly more important than A_j	$\widetilde{8} = (7,8,9)$	(1/9, 1/8, 1/7)
A_i is extremely strongly more important than A_j	$\widetilde{9} = (8,9,9)$	(1/9, 1/9, 1/8)

satisfying $\tilde{d}_{ii}^{k} = (1,1,1)$ and $\tilde{d}_{ij}^{k} = 1/\tilde{d}_{ji}^{k}$ $i,j = 1,2,\ldots,n$.

Step 6. Calculate fuzzy weights. According to Buckley [51], the geometric mean of fuzzy comparison values is used to obtain the fuzzy weights of criteria and sub-criteria by applying Eqs. (3) and (4).

$$\tilde{r}_i = (\tilde{M}_{i1} \otimes \tilde{M}_{i2} \otimes \cdots \otimes \tilde{M}_{in})^{\frac{1}{n}} \tag{3}$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \forall \mathrm{i} = 1,2,\ldots,\mathrm{n} \tag{4}$$

where $\tilde{M}_{ij}$ is the fuzzy comparison value of criterion i to criterion j, $\tilde{r}_i$ the geometric mean of the fuzzy comparison value of criterion i with respect to each criterion, and $\tilde{w}_i$ the fuzzy weight of the criterion i.

Step 7. Apply the defuzzification method. $\tilde{w}_i$ must be represented as a crisp number, for which different methods are available. In this study, the most commonly used defuzzification method, called the centre of area or centroid method will be applied. This method determines the centre of area of a fuzzy set and returns the corresponding crisp value by applying Eq. (5). This method is simple to apply and is considered the most suitable for type-1 and type-2 fuzzy sets [112].

$$w_i = (l_i + m_i + u_i)/3, i = 1,2,\ldots,n \tag{5}$$

Step 8. Normalise the weightings. The weight w_i should be normalised using Eq. (6).

$$z_i = \frac{w_i}{\sum_i^n w_i}, i = 1,2,\ldots,n \tag{6}$$

Step 9. Check consistency. Let $\tilde{R} = [\tilde{r}_{ij}]$ be a fuzzy positive reciprocal judgement matrix composed of triangular fuzzy numbers $\tilde{r}_{ij} = \left(\alpha_{ij}, \beta_{ij}, \gamma_{ij}\right)$, from which the defuzzified positive reciprocal matrix $R = \left(\beta_{ij}\right)$ can be generated. $\tilde{R}$ is consistent if R is consistent ([50, 102]). To quantify the inconsistency of the judgements given in each pairwise matrix, Saaty (1980) proposed calculating a Consistency Ratio *(CR)* from the quotient for a matrix of equal size of a Consistency Index (*CI*) and a Random Consistency Index (*RCI*) generated by simulation. The judgement is considered consistent if *CR* is less than 0.05 for a 3 × 3 matrix, 0.08 for a 4 × 4 matrix or 0.1 for matrices with a dimension greater than 4 [113]. If the CR exceeds the previous values, the judgements provided by the decision makers are not valid and it is necessary to re-evaluate the pairwise comparisons [107].

4. Research methodology

The choice of fuzzy AHP, rather than another multicriteria technique, such as one belonging to the ELECTRE or PROMETHEE families of techniques or Data Envelopment analysis (DEA), was made for the following reasons:

- Fuzzy AHP is a popular practical methodology for dealing with uncertainty, vagueness, doubts or imprecisions or elements not precisely measurable, issues inherent to the decision maker's mental process in making judgments. The maintenance field is especially affected by fuzziness, due to the historical lack of accurate data, and the use instead of information from experts who are responsible for maintenance practice in their industries [114].
- Fuzzy AHP allows the systematic structuring of a complex problem by building a hierarchy in which the objective is placed at the top, followed by the criteria, sub-criteria, or alternatives. It outperforms other MCDM methods in this area [112]. Taking into account that in this study it has been necessary to use a large number of sub-criteria (40) organised into 8 criteria, as well as 15 alternatives, the use of a hierarchical structure is very helpful to facilitate the visualisation of the elements that make up the model, and guarantee the independence of the criteria and sub-criteria used.
- Fuzzy AHP has great flexibility that allows it to be combined or integrated with a wide range of techniques (especially Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), but also linear programming, the Taguchi loss function, neural networks, genetic algorithms, principal component analysis, Monte Carlo simulation, etc.) and for very different purposes [115]. In this research, this flexibility has allowed it to be combined with utility theory and the use of Monte Carlo simulation to achieve the desired results.
- Fuzzy AHP uses pairwise comparisons, which are often preferred by the decision makers, allowing them to derive weights of criteria and scores of alternatives from comparison matrices rather than quantifying weights directly [117].
- It has had a huge number of applications in recent years, and is the second most-used technique in the literature in isolation or independently (after AHP) and the most applied in the diffuse field [115]. In the specific field of maintenance, in which this research is framed, it is also the second most applied MCDM method after AHP [116]. This broad application with effective results in many real-life problems provides greater confidence in the results obtained from its application.
- It allows a complete classification of alternatives (something which is not the case with other multicriteria techniques such as ELECTRE I and PROMETHEE I).
- Fuzzy AHP has been applied in the literature fundamentally with the goal of assessment- as in this study- in addition to selection, in the fields of manufacturing, industry and government [115]. One of these fields can be considered to be included in the current

study, since most of the buildings belong to government organisations, or provide public services such as hospitals, research or teaching centers such as universities.

- Like AHP, fuzzy AHP provides a measure of consistency in fuzzy pairwise comparison matrices, a feature that most multicriteria techniques lack. Having a limit of 10 % for the inconsistency allowed in the pairwise comparison matrices forces a rethink of the judgments made by the decision maker, thereby reducing the final inconsistency of the result.
- Although Chang's extent analysis is the most commonly used methodology in the literature for weight derivation in fuzzy pairwise comparison matrices, it also performed less well compared to other methods [118]. Therefore, in this study, Buckley's methodology has been used to define criteria weights, because it is more practical to extend it to the fuzzy environment, and it assures a single solution to the comparison matrix. Additionally, its application is relatively easier than the other fuzzy AHP approaches [119].
- Furthermore, the integration of fuzzy AHP with the Monte Carlo simulation is due to the fact that it allows the most probable response to be obtained, and the uncertainty of the model designed to be estimated. This is a complex function of 40 discrete

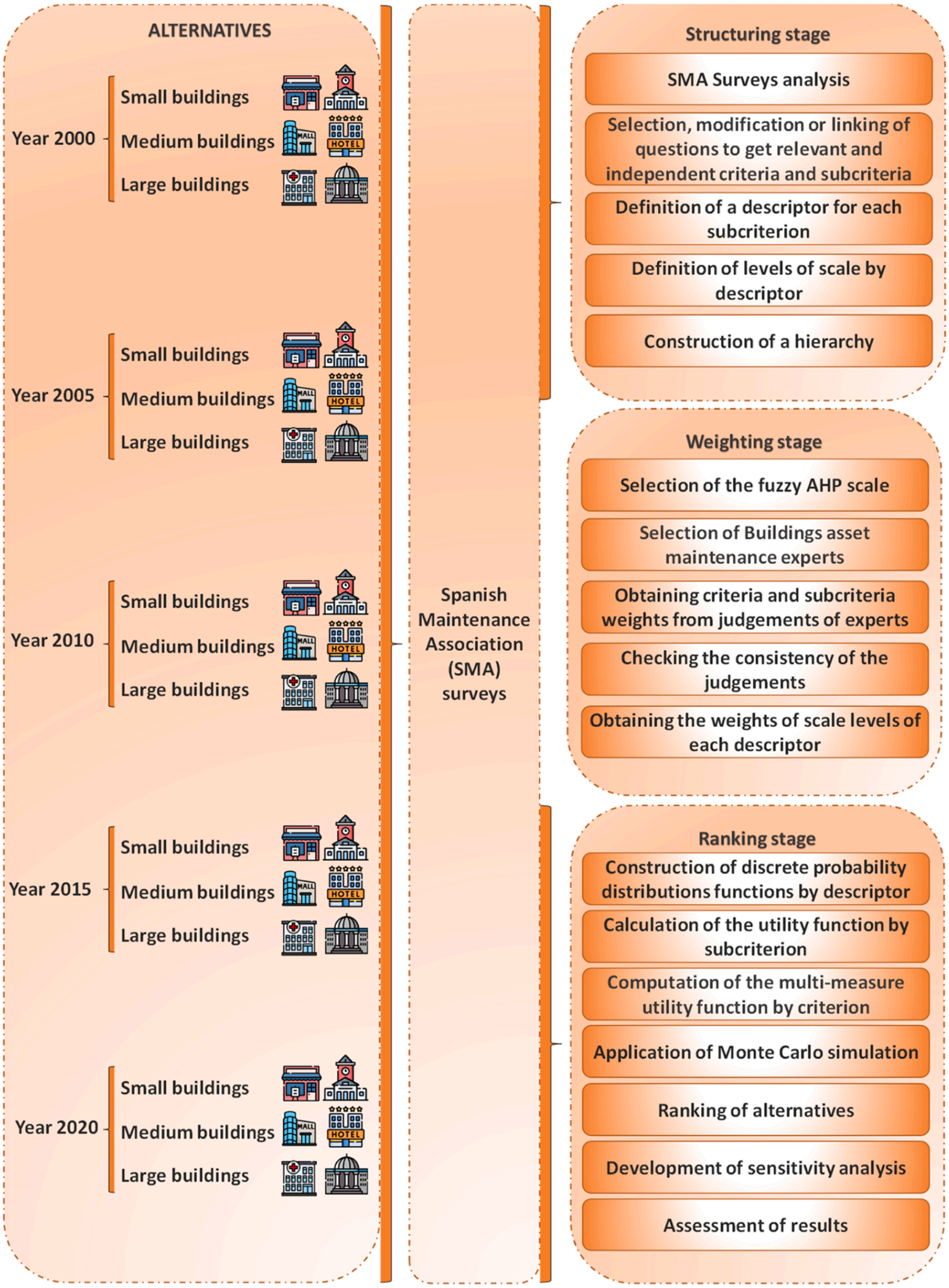

Fig. 1. Flowchart of the research methodology.

probability distribution functions by alternative (in this study, discrete probability functions particularised for the data obtained from the surveys), repeating the calculation for the 15 alternatives analysed. The integration of fuzzy AHP with utility theory and the Monte Carlo simulation provides a model with greater robustness, efficiency and effectiveness by taking into account the strengths of each technique or method and allows a prediction to be obtained based on the computation of multiple discrete probability distributions which could not otherwise be used as data.

Other MCDM methods, such as VIsekriterijumskaopticija i KOmpromisno Resenje (VIKOR) or TOPSIS are based on an aggregating function representing closeness to the ideal alternative and distance to the anti-ideal solution. Thus, they are distance-based tools, and at the same time recognised as a compromise-based method [120]. Although they are methods widely used in the literature and with excellent results in the classification of alternatives, as well as having versions in the fuzzy environment, they suffer from some deficiencies for the purposes of this research, mainly related to the lack of a systematic hierarchical structure, a procedure for calculating weights for the criteria and sub-criteria, and for checking the inconsistency of the judgements issued by the decision makers ([121, 122]). Additionally, TOPSIS does not consider the relative importance of distances [122]. For its part, Combined Compromise Solution (CoCoSo) is a compendium of compromise solutions based on an integrated simple additive weighting and exponentially weighted product model, although it does not have an extension in the fuzzy domain [123], which is necessary for this study.

Fig. 1 describes the research methodology used within the study. The research methodology applied is structured into the following main stages:

- Structuring stage. This first stage carries out a broad analysis of the Spanish sectoral surveys of the SMA from 2000–2020 is carried out. A study must first be carried out to guarantee the uniformity of the data, since the surveys used contain a different number of questions, ranging from 56 in 2000–128 questions in 2020. Therefore, it must be ensured that the same questions are used throughout the different surveys. Subsequently, it is necessary to select, modify or link the questions to convert them into sub-criteria so that they are exhaustive, concise, non-redundant and independent, fulfilling the conditions established by Keeney [124]. Next, a descriptor and its scale levels will be defined that allow each sub-criterion to be evaluated without ambiguity. The structuring of the sub-criteria within the criteria allows the creation of the hierarchy.
- Weighting stage. This is related to obtaining the different weightings that will be used in the model, for which the judgements of four experts in building asset management are used. Fuzzy AHP, using the geometric mean method proposed by Buckley, is applied to obtain the criteria and sub-criteria weights. For the weighting of the scale levels of each descriptor, the judgements of an expert are used, with utility functions, so that the utility of the preferred scale level is 1, and the utility of the least preferred scale level is 0. In this way, different descriptors can be combined, since they originally do not use common scales.
- Ranking stage. Multi-Attribute Utility Theory (MAUT) [125] allows evaluations to be transformed into utility functions. It is necessary to calculate the utility function by sub-criterion U(y). Let U(x) be the utility associated with a scale level x of a descriptor, and p(x) the probability assigned to said scale level for a given alternative, then the value of equivalent certainty for each alternative is obtained from the expected utility by summing U(x)*p(x) for all levels x (see Eq. 7).

$$\begin{aligned} U(y) = {} & \text{utility}(\text{best scale level})^{*}\text{probability of best scale level in alternative} + \ldots \\ & + \text{utility}(\text{worst scale level})^{*}\text{probability of worst scale level in alternative} \end{aligned} \tag{7}$$

From the survey data, discrete probability distribution functions are constructed for each descriptor (or subcriterion) so that the U (y) can be calculated. A discrete probability distribution function has probabilities defined for several different levels so that the sum of these probabilities is unity. The final utility of a criterion in an alternative is calculated by a multi-measure utility function. The multi-measure utility function is obtained by multiplying the weights of each sub-criterion by the U(y) previously obtained for each sub-criterion. The application of the Monte Carlo Simulation to the model allows the uncertainty of a complex function resulting from a set of probability distributions functions, and the final uncertainty of the model, to be estimated. The application of fuzzy AHP allows the ranking of alternatives to be calculated, and finally the sensitivity analysis ensures that the model is robust against logical changes in the weighting of criteria and sub-criteria.

The Spanish Maintenance Association (SMA) carries out sectoral surveys every five years on the state of maintenance in Spain. This research uses those carried out in 2000, 2005, 2020, 2015 (on-line) and 2020 (on-line and carried out during the SARS-CoV2 pandemic period) [126–130].

Over these 20 years, some survey questions have been eliminated, modified and new ones included. However, to perform this evolutionary study, the same concepts have been maintained over time. It should be noted that, in the 2000 survey, the buildings sector is not explicitly included, but rather there is a services sector containing companies and organisations from the public administration, shopping centres, financial institutions, department stores, catering and tourism, and public services. However, since all the companies and organisations indicated are characterised by operating in buildings, this sector has been considered as the buildings sector. In the other surveys a buildings sector does appear explicitly (the services sector that existed in the year 2000 having disappeared).

The data related to the surveys in the Buildings sector carried out by the SMA are shown in Table 3. The responses to the surveys are classified according to the size of the company, into small, medium and large companies (buildings), whose definition is given by The EU in Annex I of Regulation (EU) 651/2014 [131] as shown in Table 4. The questionnaire was sent to periodically updated contacts of the SMA, and the information received was treated anonymously, making any type of identification impossible.

5. Fuzzy AHP model for assessing asset management in Spanish buildings

Firstly, the process of structuring the asset management model, the weighting process, will be described, followed by the definition of alternatives.

5.1. Structuring

In the structuring process, a broad analysis of the surveys carried out by SMA from 2000 to 2020 was performed. Not all the questions can be included in the model since it is necessary that each person surveyed can only select one option from among those on offer, and not several of them (for example, "What three values do you appreciate most in a service company?"). In addition, questions that imply an opinion and not specific data related to the company have not been included (for example, "What will be, in your workplace, the likelihood of production staff participate in maintenance work in the next few years?"). Questions whose answers might depend on others have also been eliminated. In addition, in the 2020 survey, the number of questions in the questionnaire had increased by 128 % compared to 2000. Most of them had not been included in the surveys of other years, and so they are not useful for to analysing the evolution of the sector over 20 years. Finally, after the selection process, and having checked that they meet the standard to be considered as criteria, a hierarchy was obtained comprising the goal: assessment of Spanish buildings maintenance evolution (2000–2020). The significant questions of the surveys maintained over time and that could be transferred to sub-criteria are, finally, 40 sub-criteria organised into 8 criteria. There are also 15 alternatives, 3 alternatives (small, medium and large size buildings) per survey analysed. The hierarchy is shown in Fig. 2.

The criteria and sub-criteria that make up the model are as follows:

1. Annual Maintenance Cost (AMC). This criterion includes the sub-criteria:

- C_{AMC1}. Total annual maintenance costs of the company.
- C_{AMC2}. Percentage of annual cost related to in-house staff.
- C_{AMC3}. Percentage of annual cost related to outsourcing jobs.
- C_{AMC4}. Percentage of annual cost related to spare parts and consumables.

2. Certification in International Standards and compliance with Spanish regulations on health and safety at work (CIS). The following sub-criteria are assessed:

- C_{CIS1}. Existence of a department in the company for compliance with Spanish regulations on health and safety at work.
- C_{CIS2}. Certification in standard ISO 9000.
- C_{CIS3}. Certification in standard ISO 14000.

3. Control of Maintenance Activities and efficiency (CMA):

- C_{CMA1}. Organisation of work in work orders.
- C_{CMA2}. Use of KPIs for systematic control of the evolution asset management (C_{CMA2}).
- C_{CMA3}. Delay in receipt of information on costs.
- C_{CMA4}. Regularity of receipt of information on maintenance costs.
- C_{CMA5}. Percentage of corrective maintenance undertaken annually vs. preventive maintenance.
- C_{CMA6}. Percentage of urgent work received.
- C_{CMA7}. Pending work.

4. Maintenance Manager Characteristics and maintenance tasks outside working hours (MMC). This includes the following sub-criteria:

- C_{MMC1}. Length of time as maintenance manager (this looks at the total time in that post, and in the current and other companies).
- C_{MMC2}. Academic qualifications of head of maintenance.

Table 3
Survey data [126–130].

Years	2000	2005	2010	2015	2020
Questionnaires sent out	515	95	138	233	312
Questionnaires received	52	24	17	71	65
Answer percentage	10.10 %	25.26 %	12.32 %	30.47	20.83 %
Average staff per company	350	440	650	369	296
Date carried out	01/02/2000 to 30/04/2000	01/02/2005 to 30/04/2005	15/02/2010 to 31/05/2010	22/07/2015–31/10/2015	30/12/2019–16/06/2020

Table 4
Classification of companies by size (created by the author from Annex I of Regulation (EU) 651/2014 of the Commission).

Size	Number of workers	Annual turnover (€ Millions)	Annual profit (€ Millions)
Small enterprise	<50	≤10	≤10
Medium enterprise	<250	≤50	≤43
Large enterprise	≥250	>50	>43

[1] In order for a company to be classified in one category or another, it must satisfy the requirement for the number of employees, and also one of the other two criteria.

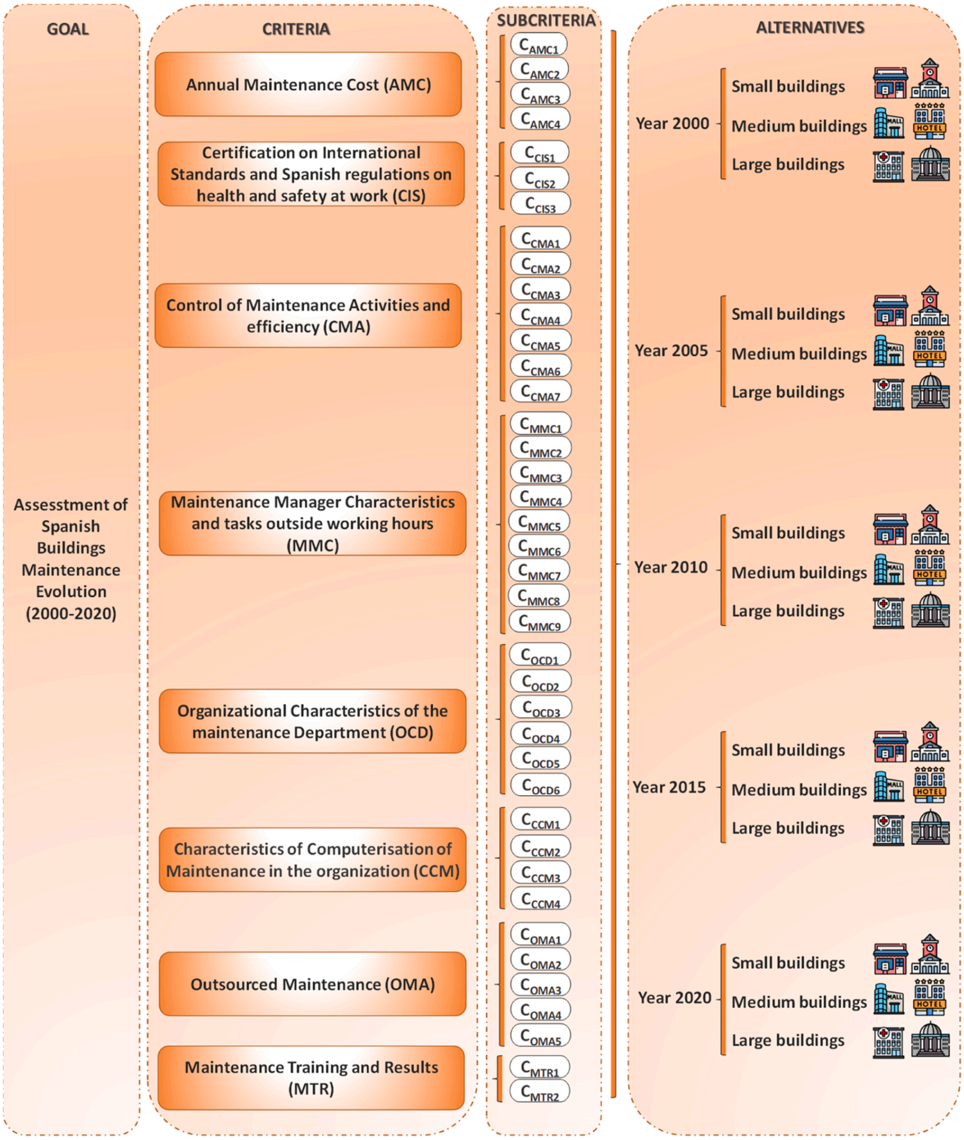

Fig. 2. Hierarchy.

- C_{MMC3}. Length of time as member of a maintenance department (in any post, and in the current of other companies).
- C_{MMC4}. Frequency with which the head of maintenance is required to attend outside working hours to resolve maintenance incidents that cannot be sorted out by others, because they are not there or because of the difficulty of the incident.
- C_{MMC5}. Remuneration for overtime work or work outside working hours.
- C_{MMC6}. Attendance at conferences, talks, seminars, etc. on maintenance.
- C_{MMC7}. Consulting Spanish technical journals on maintenance.
- C_{MMC8}. Use of the internet to search for information to solve maintenance problems.

- C_{MMC9}. Consulting international technical journals on maintenance.

5. Organisational Characteristics of the maintenance Department (OCD). This comprises the following sub-criteria:

- C_{OCD1}. Existence of a maintenance department or area.
- C_{OCD2}. Dependence hierarchy of the maintenance department.
- C_{OCD3}. Functions assigned to the maintenance department.
- C_{OCD4}. Number of staff specific to the maintenance department.
- C_{OCD5}. Existence of an organisation to solve incidents outside working hours.
- C_{OCD6}. Collaboration of the production staff in maintenance activities.

6. Characteristics of Computerisation of Maintenance in the organisation (CCM). The following sub-criteria are considered:

- C_{CCM1}. Level of satisfaction in the application of computerisation.
- C_{CCM2}. Number of activities in which computerisation is used.
- C_{CCM3}. Typology of Computerised Maintenance Management System (CMMS) used.
- C_{CCM4}. Hardware on which maintenance software runs.

7. Outsourced Maintenance (OMA). This comprises the following sub-criteria:

- C_{OMA1}. Annual percentage of corrective maintenance outsourced.
- C_{OMA2}. Annual percentage of preventive maintenance outsourced.
- C_{OMA3}. Annual percentage of work from programmed stoppages outsourced.
- C_{IOM4}. Quality of work outsourced.
- C_{IOM5}. Annual percentage of outsourced personnel.

8. Maintenance Training and Results (MTR). The following sub-criteria are assessed:

- C_{MTR1}. Training courses.
- C_{MTR2}. Versatility of staff.

Since the elements to be assessed are sub-criteria, each must have a descriptor associated with it. A descriptor is defined by Bana e Costa et al. [132], as an ordered set of impact levels that can measure quantitatively or qualitatively the level of fulfillment of a criterion. The descriptors defined in this model are generally qualitative, although there are also some quantitative ones. Table 5 shows, as an example, the descriptors and scale levels defined for the Percentage of urgent work received (C_{CMA6}) and Pending work (C_{CMA7}) sub-criteria, both included in the criterion Control of Maintenance Activities and efficiency (CMA).

5.2. Weighting process

The judgements used to obtain the weighting of the criteria and sub-criteria were obtained from four experts in buildings asset management. Two of these experts have more than twenty-five years of experience in the practical management of the maintenance of different facilities. The other two experts also have experience in buildings maintenance, also over twenty-five years in one case and ten years in another, are involved with universities. Three of them have doctoral degrees and one has two higher degrees, one in a branch of engineering. There is parity in the decision-making group. The experts individually filled out a questionnaire that included information about how to go through the decision-making process, and used the scale shown in Table 2 (see Section 3) to make their judgements. This scale is adapted to the original crisp AHP scale proposed by Saaty [133].

Table 5
Descriptors and scale levels of sub-criteria Percentage of urgent work received (C_{CMA6}) and Pending work (C_{CMA7}).

Descriptor: Percentage of annual maintenance jobs received marked maximum urgency	
Level 1 (highest level of performance)	From 0 % to 5 %
Level 2	From 6 % to 15 %
Level 3	From 16 % to 30 %
Level 4	From 31 % to 50 %
Level 5 (lowest level of performance)	Over 50 %
Descriptor: Time it would take the maintenance department to finish all jobs, current, on hold and pending	
Level 1 (highest level of performance)	Less than a week
Level 2	From one to two weeks
Level 3	From two weeks to a month
Level 4	From one to two months
Level 5	From two to four months
Level 6 (lowest level of performance)	Over four months

Table 6
Aggregated pairwise comparison matrix of criteria.

Criteria	**AMC**	**CIS**	CMA	MMC	**OCD**	**CCM**	**OMA**	**MTR**
AMC	**(1.000, 1.000, 1.000)**	(1.934, 3.130, 4.243)	(1.316, 1.682, 1.968)	(2.000, 3.080, 4.120)	(3.464, 4.472, 5.477)	(4.000, 5.097, 6.000)	(6.055, 7.085, 7.896)	(5.886, 6.901, 7.707)
CIS	(0.236, 0.319, 0.517)	**(1.000, 1.000, 1.000)**	(0.485, 0.562, 0.707)	(0.485, 0.795, 1.225)	(1.000, 1.480, 1.968)	(1.189, 1.861, 2.783)	(3.080, 4.281, 5.384)	(1.807, 2.475, 3.464)
CMA	(0.508, 0.595, 0.760)	(1.414, 1.778, 2.060)	**(1.000, 1.000, 1.000)**	(1.000, 1.565, 2.213)	(1.189, 1.495, 1.861)	(1.861, 2.913, 3.936)	(3.600, 4.681, 5.733)	(3.557, 4.606, 5.635)
MMC	(0.243, 0.325, 0.500)	(0.816, 1.257, 2.060)	(0.452, 0.639, 1.000)	**(1.000, 1.000, 1.000)**	(0.841, 1.414, 2.060)	(1.682, 2.340, 2.913)	(2.991, 4.054, 5.091)	(2.213, 2.783, 3.310)
OCD	(0.183, 0.224, 0.289)	(0.508, 0.676, 1.000)	(0.537, 0.669, 0.841)	(0.485, 0.707, 1.189)	**(1.000, 1.000, 1.000)**	(0.841, 1.414, 2.060)	(2.000, 3.162, 4.243)	(1.682, 2.280, 2.828)
CCM	(0.167, 0.196, 0.250)	(0.359, 0.537, 0.841)	(0.254, 0.343, 0.537)	(0.343, 0.427, 0.595)	(0.485, 0.707, 1.189)	**(1.000, 1.000, 1.000)**	(2.378, 2.943, 3.464)	(1.000, 1.565, 2.213)
OMA	(0.127, 0.141, 0.165)	(0.186, 0.234, 0.325)	(0.174, 0.214, 0.278)	(0.196, 0.247, 0.334)	(0.236, 0.316, 0.500)	(0.289, 0.340, 0.420)	**(1.000, 1.000, 1.000)**	(0.380, 0.577, 0.931)
MTR	(0.130, 0.145, 0.170)	(0.289, 0.404, 0.553)	(0.177, 0.217, 0.281)	(0.302, 0.359, 0.452)	(0.354, 0.439, 0.595)	(0.452, 0.639, 1.000)	(1.075, 1.732, 2.632)	**(1.000, 1.000, 1.000)**

The judgement matrices provided by the Decision Makers (DM) to obtain the weighting of the criteria are the following:

$$
\begin{array}{rc}
\mathbf{DM\#1} & \begin{array}{cccccccc} \text{AMC} & \text{CIS} & \text{CMA} & \text{MMC} & \text{OCD} & \text{CCM} & \text{OMA} & \text{MTR} \end{array} \\
\begin{array}{r} \text{AMC} \\ \text{CIS} \\ \text{CMA} \\ \text{MMC} \\ \text{OCD} \\ \text{CCM} \\ \text{OMA} \\ \text{MTR} \end{array} &
\begin{bmatrix}
\tilde{1} & \tilde{2} & \tilde{2} & \tilde{3} & \tilde{4} & \tilde{5} & \tilde{5} & \tilde{7} \\
\tilde{2}^{-1} & \tilde{1} & \tilde{1} & \tilde{2} & \tilde{3} & \tilde{4} & \tilde{4} & \tilde{5} \\
\tilde{2}^{-1} & \tilde{1} & \tilde{1} & \tilde{2} & \tilde{3} & \tilde{4} & \tilde{4} & \tilde{5} \\
\tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{2} & \tilde{3} & \tilde{3} & \tilde{4} \\
\tilde{4}^{-1} & \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{2} & \tilde{2} & \tilde{3} \\
\tilde{5}^{-1} & \tilde{4}^{-1} & \tilde{4}^{-1} & \tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{1} & \tilde{3} \\
\tilde{5}^{-1} & \tilde{4}^{-1} & \tilde{4}^{-1} & \tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{1} & \tilde{2} \\
\tilde{7}^{-1} & \tilde{5}^{-1} & \tilde{5}^{-1} & \tilde{4}^{-1} & \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{1}
\end{bmatrix}
\end{array}
$$

$$
\begin{array}{rc}
\mathbf{DM\#2} & \begin{array}{cccccccc} \text{AMC} & \text{CIS} & \text{CMA} & \text{MMC} & \text{OCD} & \text{CCM} & \text{OMA} & \text{MTR} \end{array} \\
\begin{array}{r} \text{AMC} \\ \text{CIS} \\ \text{CMA} \\ \text{MMC} \\ \text{OCD} \\ \text{CCM} \\ \text{OMA} \\ \text{MTR} \end{array} &
\begin{bmatrix}
\tilde{1} & \tilde{2} & \tilde{1} & \tilde{3} & \tilde{5} & \tilde{3} & \tilde{8} & \tilde{6} \\
\tilde{2}^{-1} & \tilde{1} & \tilde{2}^{-1} & \tilde{2} & \tilde{4} & \tilde{2} & \tilde{7} & \tilde{5} \\
\tilde{1} & \tilde{2} & \tilde{1} & \tilde{3} & \tilde{5} & \tilde{3} & \tilde{8} & \tilde{6} \\
\tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{3}^{-1} & \tilde{1} & \tilde{2} & \tilde{1} & \tilde{5} & \tilde{3} \\
\tilde{5}^{-1} & \tilde{4}^{-1} & \tilde{5}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{3}^{-1} & \tilde{2} & \tilde{1} \\
\tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{3}^{-1} & \tilde{1} & \tilde{3} & \tilde{1} & \tilde{5} & \tilde{3} \\
\tilde{8}^{-1} & \tilde{7}^{-1} & \tilde{8}^{-1} & \tilde{5}^{-1} & \tilde{2}^{-1} & \tilde{5}^{-1} & \tilde{1} & \tilde{2}^{-1} \\
\tilde{6}^{-1} & \tilde{5}^{-1} & \tilde{6}^{-1} & \tilde{3}^{-1} & \tilde{1} & \widetilde{\tilde{3}^{-1}} & \tilde{2} & \tilde{1}
\end{bmatrix}
\end{array}
$$

$$
\begin{array}{rc}
\mathbf{DM\#3} & \begin{array}{cccccccc} \text{AMC} & \text{CIS} & \text{CMA} & \text{MMC} & \text{OCD} & \text{CCM} & \text{OMA} & \text{MTR} \end{array} \\
\begin{array}{r} \text{AMC} \\ \text{CIS} \\ \text{CMA} \\ \text{MMC} \\ \text{OCD} \\ \text{CCM} \\ \text{OMA} \\ \text{MTR} \end{array} &
\begin{bmatrix}
\tilde{1} & \tilde{8} & \tilde{1} & \tilde{5} & \tilde{5} & \tilde{9} & \tilde{9} & \tilde{9} \\
\tilde{8}^{-1} & \tilde{1} & \tilde{5}^{-1} & \tilde{5}^{-1} & \tilde{5}^{-1} & \tilde{2}^{-1} & \tilde{2} & \tilde{2}^{-1} \\
\tilde{1} & \tilde{5} & \tilde{1} & \tilde{3} & \tilde{3}^{-1} & \tilde{2} & \tilde{3} & \tilde{5} \\
\tilde{5}^{-1} & \tilde{5} & \tilde{3}^{-1} & \tilde{1} & \tilde{3}^{-1} & \tilde{2} & \tilde{3} & \tilde{1} \\
\tilde{5}^{-1} & \tilde{5} & \tilde{3} & \tilde{3} & \tilde{1} & \tilde{3} & \tilde{5} & \tilde{3} \\
\tilde{9}^{-1} & \tilde{2} & \tilde{2}^{-1} & \tilde{2} & \tilde{3}^{-1} & \tilde{1} & \tilde{5} & \tilde{3}^{-1} \\
\tilde{9}^{-1} & \tilde{2}^{-1} & \tilde{3}^{-1} & \tilde{3} & \tilde{5}^{-1} & \tilde{1} & \tilde{1} & \tilde{3}^{-1} \\
\tilde{9}^{-1} & \tilde{2} & \tilde{5}^{-1} & \tilde{1} & \tilde{3}^{-1} & \tilde{5}^{-1} & \tilde{3} & \tilde{1}
\end{bmatrix}
\end{array}
$$

$$
\begin{array}{rc}
\mathbf{DM\#4} & \begin{array}{cccccccc} \text{AMC} & \text{CIS} & \text{CMA} & \text{MMC} & \text{OCD} & \text{CCM} & \text{OMA} & \text{MTR} \end{array} \\
\begin{array}{r} \text{AMC} \\ \text{CIS} \\ \text{CMA} \\ \text{MMC} \\ \text{OCD} \\ \text{CCM} \\ \text{OMA} \\ \text{MTR} \end{array} &
\begin{bmatrix}
\tilde{1} & \tilde{3} & \tilde{4} & \tilde{2} & \tilde{4} & \tilde{5} & \tilde{7} & \tilde{6} \\
\tilde{3}^{-1} & \tilde{1} & \tilde{1} & \tilde{2}^{-1} & \tilde{2} & \tilde{3} & \tilde{6} & \tilde{3} \\
\tilde{4}^{-1} & \tilde{1} & \tilde{1} & \tilde{3}^{-1} & \tilde{1} & \tilde{3} & \tilde{5} & \tilde{3} \\
\tilde{2}^{-1} & \tilde{2} & \tilde{3} & \tilde{1} & \tilde{2} & \tilde{5} & \tilde{6} & \tilde{5} \\
\tilde{4}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{3}^{-1} & \tilde{1} & \tilde{2} & \tilde{5} & \tilde{3} \\
\tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{5}^{-1} & \tilde{2}^{-1} & \tilde{1} & \tilde{3} & \tilde{2} \\
\tilde{7}^{-1} & \tilde{6}^{-1} & \tilde{5}^{-1} & \tilde{6}^{-1} & \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{1} & \tilde{3}^{-1} \\
\tilde{6}^{-1} & \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{2}^{-1} & \tilde{3} & \tilde{1}
\end{bmatrix}
\end{array}
$$

.

Given a fuzzy number $\widetilde{d}_{ij}^{k} = \left(l_{ij}^{k}, m_{ij}^{k}, u_{ij}^{k}\right)$ from the previous fuzzy pairwise comparison matrix given by decision maker k, To aggregate the judgements provided by a set of decision makers (k = 1, 2, …, K), the geometric mean of K decision makers' judgement values is calculated as shown in Eq. (8). The geometric mean is used instead of the arithmetic mean because, according to Liu et al. [112], it is simple to apply, since it only requires arithmetic multiplication and taking roots, and performs better than the arithmetic mean. The aggregate judgement matrix of the four experts for the criteria is shown in Table 6.

$$
l_{ij} = \left(\prod_{k=1}^{K} l_{ij}^{k}\right)^{1/K}, \quad m_{ij} = \left(\prod_{k=1}^{K} m_{ij}^{k}\right)^{1/K}, \quad u_{ij} = \left(\prod_{k=1}^{K} u_{ij}^{k}\right)^{1/K} \tag{8}
$$

Eq. (3) is applied to the pairwise comparison matrix of the experts' aggregated judgements from Table 6, to calculate their geometric means by rows: $\widetilde{r}_{AMC} = (2.661, 3.405, 4.024)$, $\widetilde{r}_{CIS} = (0.882, 1.195, 1.613)$, $\widetilde{r}_{CMA} = (1.458, 1.879, 2.313)$, $\widetilde{r}_{MMC} = (0.978, 1.3291.787)$, $\widetilde{r}_{OCD} = (0.715, 0.961, 1.278)$, $\widetilde{r}_{CCM} = (0.528, 0.688, 0.941)$, $\widetilde{r}_{OMA} = (0.260, 0.319, 0.420)$ and $\widetilde{r}_{MTR} = (0.369, 0.466, 0.608)$.

Next, applying Eq. (4) gives the fuzzy weights of the criteria: $\widetilde{w}_{AMC} = (0.205, 0.332, 0.513)$, $\widetilde{w}_{CIS} = (0.068, 0.117, 0.205)$, $\widetilde{w}_{CMA} =$

Table 7
Final non-fuzzy weights of sub-criteria.

Criteria	Subcriteria	$\tilde{r}_i$	Normalised crisp weights
Annual Maintenance Cost (AMC)	C_{AMC1}	$\tilde{r}_{AMC1} = (1.570, 1.904, 2.188)$	$w_{AMC1} = 0.388$
	C_{AMC2}	$\tilde{r}_{AMC2} = (1.488, 1.854, 2.217)$	$w_{AMC2} = 0.383$
	C_{AMC3}	$\tilde{r}_{AMC3} = (0.419, 0.530, 0.677)$	$w_{AMC3} = 0.113$
	C_{AMC4}	$\tilde{r}_{AMC4} = (0.446, 0.534, 0.697)$	$w_{AMC4} = 0.116$
Certification on International Standards and Spanish regulations on health and safety at work (CIS)	C_{CIS1}	$\tilde{r}_{CIS1} = (0.841, 0.954, 1.079)$	$w_{CIS1} = 0.261$
	C_{CIS2}	$\tilde{r}_{CIS2} = (0.419, 0.464, 0.530)$	$w_{CIS2} = 0.128$
	C_{CIS3}	$\tilde{r}_{CIS3} = (1.997, 2.259, 2.484)$	$w_{CIS3} = 0.611$
Control of Maintenance Activities and efficiency (CMA)	C_{CMA1}	$\tilde{r}_{CMA1} = (1.972, 2.327, 2.679)$	$w_{CMA1} = 0.287$
	C_{CMA2}	$\tilde{r}_{CMA2} = (1.499, 1.765, 2.058)$	$w_{CMA2} = 0.219$
	C_{CMA3}	$\tilde{r}_{CMA3} = (0.875, 1.071, 1.304)$	$w_{CMA3} = 0.134$
	C_{CMA4}	$\tilde{r}_{CMA4} = (0.610, 0.688, 0.777)$	$w_{CMA4} = 0.085$
	C_{CMA5}	$\tilde{r}_{CMA5} = (0.403, 0.460, 0.549)$	$w_{CMA5} = 0.058$
	C_{CMA6}	$\tilde{r}_{CMA6} = (0.592, 0.696, 0.818)$	$w_{CMA6} = 0.087$
	C_{CMA7}	$\tilde{r}_{CMA7} = (0.878, 1.031, 1.208)$	$w_{CMA7} = 0.129$
Maintenance Manager Characteristics and tasks outside working hours (MMC)	C_{MMC1}	$\tilde{r}_{MMC1} = (2.008, 2.385, 2.821)$	$w_{MMC1} = 0.208$
	C_{MMC2}	$\tilde{r}_{MMC2} = (1.435, 1.755, 2.114)$	$w_{MMC2} = 0.153$
	C_{MMC3}	$\tilde{r}_{MMC3} = (2.321, 2.901, 3.494)$	$w_{MMC3} = 0.252$
	C_{MMC4}	$\tilde{r}_{MMC4} = (1.140, 1.414, 1.720)$	$w_{MMC4} = 0.124$
	C_{MMC5}	$\tilde{r}_{MMC5} = (0.656, 0.823, 1.007)$	$w_{MMC5} = 0.072$
	C_{MMC6}	$\tilde{r}_{MMC6} = (0.639, 0.827, 1.028)$	$w_{MMC6} = 0.072$
	C_{MMC7}	$\tilde{r}_{MMC7} = (0.378, 0.451, 0.567)$	$w_{MMC7} = 0.040$
	C_{MMC8}	$\tilde{r}_{MMC8} = (0.298, 0.361, 0.462)$	$w_{MMC8} = 0.033$
	C_{MMC9}	$\tilde{r}_{MMC9} = (0.393, 0.524, 0.689)$	$w_{MMC9} = 0.047$
Organisational Characteristics of the maintenance Department (OCD)	C_{OCD1}	$\tilde{r}_{OCD1} = (2.001, 2.467, 2.913)$	$w_{OCD1} = 0.347$
	C_{OCD2}	$\tilde{r}_{OCD2} = (0.757, 1.003, 1.303)$	$w_{OCD2} = 0.146$
	C_{OCD3}	$\tilde{r}_{OCD3} = (1.172, 1.465, 1.806)$	$w_{OCD3} = 0.210$
	C_{OCD4}	$\tilde{r}_{OCD4} = (0.782, 0.979, 1.248)$	$w_{OCD4} = 0.142$
	C_{OCD5}	$\tilde{r}_{OCD5} = (0.471, 0.590, 0.744)$	$w_{OCD5} = 0.085$
	C_{OCD6}	$\tilde{r}_{OCD6} = (0.383, 0.477, 0.629)$	$w_{OCD6} = 0.071$
Characteristics of Computerisation of Maintenance in the organisation (CCM)	C_{CCM1}	$\tilde{r}_{CCM1} = (2.066, 2.523, 2.968)$	$w_{CCM1} = 0.508$
	C_{CCM2}	$\tilde{r}_{CCM2} = (1.075, 1.274, 1.493)$	$w_{CCM2} = 0.258$
	C_{CCM3}	$\tilde{r}_{CCM3} = (0.558, 0.675, 0.808)$	$w_{CCM3} = 0.137$

(*continued on next page*)

Table 7 (*continued*)

Criteria	Subcriteria	$\tilde{r}_i$	Normalised crisp weights
	C_{CCM4}	$\tilde{r}_{CCM4} = (0.388, 0.461, 0.580)$	$w_{CCM4} = 0.096$
Outsourced Maintenance (OMA)	C_{OMA1}	$\tilde{r}_{OMA1} = (0.893, 1.039, 1.191)$	$w_{OMA1} = 0.193$
	C_{OMA2}	$\tilde{r}_{OMA2} = (1.011, 1.168, 1.368)$	$w_{OMA2} = 0.219$
	C_{OMA3}	$\tilde{r}_{OMA3} = (0.568, 0.684, 0.829)$	$w_{OMA3} = 0.129$
	C_{OMA4}	$\tilde{r}_{OMA4} = (1.557, 1.794, 2.048)$	$w_{OMA4} = 0.333$
	C_{OMA5}	$\tilde{r}_{OMA5} = (0.563, 0.671, 0.806)$	$w_{OMA5} = 0.126$
Maintenance Training and Results (MTR)	C_{MTR1}	$\tilde{r}_{MTR1} = (1.130, 1.316, 1.488)$	$w_{MTR1} = 0.629$
	C_{MTR2}	$\tilde{r}_{MTR2} = (0.672, 0.760, 0.885)$	$w_{MTR2} = 0.371$

$(0.112, 0.183, 0.295)$, $\tilde{w}_{MMC} = (0.075, 0.130, 0.228)$, $\tilde{w}_{OCD} = (0.055, 0.094, 0.163)$, $\tilde{w}_{CCM} = (0.041, 0.067, 0.120)$, $\tilde{w}_{OMA} = (0.020, 0.031, 0.054)$ and $\tilde{w}_{MTR} = (0.028, 0.045, 0.077)$.

Defuzzification is achieved by applying the centre of area method, and after normalisation the following crisp weights are obtained for the criteria: $\tilde{w}_{AMC} = 0.322$, $\tilde{w}_{CIS} = 0.120$, $\tilde{w}_{CMA} = 0.181$, $\tilde{w}_{MMC} = 0.133$, $\tilde{w}_{OCD} = 0.096$ $\tilde{w}_{CCM} = 0.070$, $\tilde{w}_{OMA} = 0.032$ and $\tilde{w}_{MTR} = 0.046$.

The pairwise fuzzy judgement matrices of DM#1 to DM#4 have consistency ratios of respectively 0.017, 0.010, 0.097 and 0.031. Therefore, the fuzzy aggregated judgement matrix is consistent, because if the fuzzy pairwise comparison matrices given for each decision maker are consistent, then the matrix resulting from the aggregation of the judgements is consistent [51].

A similar methodology has been applied to each set of sub-criteria within each criterion, giving the values shown in Table 7. In all cases, the CRs are less than 0.1.

Additionally, in order to evaluate each alternative, the scale levels of each descriptor must be weighted, and then transformed into a utility vector. For this, the judgements of one of the experts (DM#1), who also participated in giving the rest of the judgements, were used. In some cases, the expert considered that the utilities were distributed homogeneously between the scale levels, since the separation between the levels made it possible to establish this, while in other cases judgements were given to build a pairwise matrix on which to use AHP. Finally, everything was converted into utility vectors, assigning 1 to the utility of the preferred scale level and 0 to the least preferred scale level, for which using linear algebra to compute the best-fit set of utilities based on the ratios obtained from the decision maker. The utilities returned for the scale levels of the descriptors associated with the sub-criteria Percentage of urgent work received (C_{CMA6}) and Pending work (C_{CMA7}) are shown in Table 8. The resulting utility vector for the descriptor: Time that the maintenance department would take to finish the jobs in progress and on hold or pending is (1.0000, 0.7293, 0.3919, 0.1763, 0.0543, 0.0000). The CR of this matrix is 0.0529.

Table 8
Utility values for each scale level of the descriptors associated with the sub-criteria Percentage of urgent work received (C_{CMA6}) and Pending work (C_{CMA7}) (see Table 3).

Descriptor: Percentage of annual maintenance jobs received marked maximum urgency	
Scale levels	**Utility values**
From 0 % to 5 %	1.0000
From 6 % to 15 %	0.5342
From 16 % to 30 %	0.2549
From 31 % to 50 %	0.0925
Over 50 %	0.0000
Descriptor: Time that the maintenance department would take to finish the jobs in progress and on hold or pending	
Scale levels	**Utility values**
Less than one week	1.0000
From one to two weeks	0.7293
From two weeks to one month	0.3919
From one to two months	0.1763
From two to four months	0.0543
Over four months	0.0000

5.3. Alternatives

The alternatives are relative to the years analysed, 2000, 2005, 2010, 2015 and 2020, further broken down by size into: buildings with up to 200 workers, from 201 to 500 workers, and over 500 workers, giving 15 alternatives in all.

The model uses the data provided by the surveys carried out by the SMA in the years analysed. These data are converted into probabilities, so that each scale level of each descriptor can be associated with a probability of occurrence in each alternative evaluated. These probabilities allow a discrete probability distribution function to be built for each descriptor. These functions assign to each event defined on the random variable the probability that said event occurs, defined on the set of all possible values of the random variable.

However, due to certain particularities and the fact that certain questions have not been asked in some surveys or the data are not presented in the same way, it has been necessary to consider different ways of building the discrete probability functions:

- The 2015 and 2020 surveys give the number of unanswered questions. However, to obtain comparative results in all the surveys, all the percentages generated from the data provided were considered, without including the questions left unanswered.
- Some questions were not asked in a particular survey, but if the factor to be analysed is considered important, the question was included and the same probability assigned to all scales levels, to create the discrete probability distribution function. This is the case of the sub-criteria included in the criterion Certification in International Standards and compliance with Spanish regulations on health and safety at work, the sub-criteria of the criterion Out-sourced Maintenance carried out in the organisation, and in the

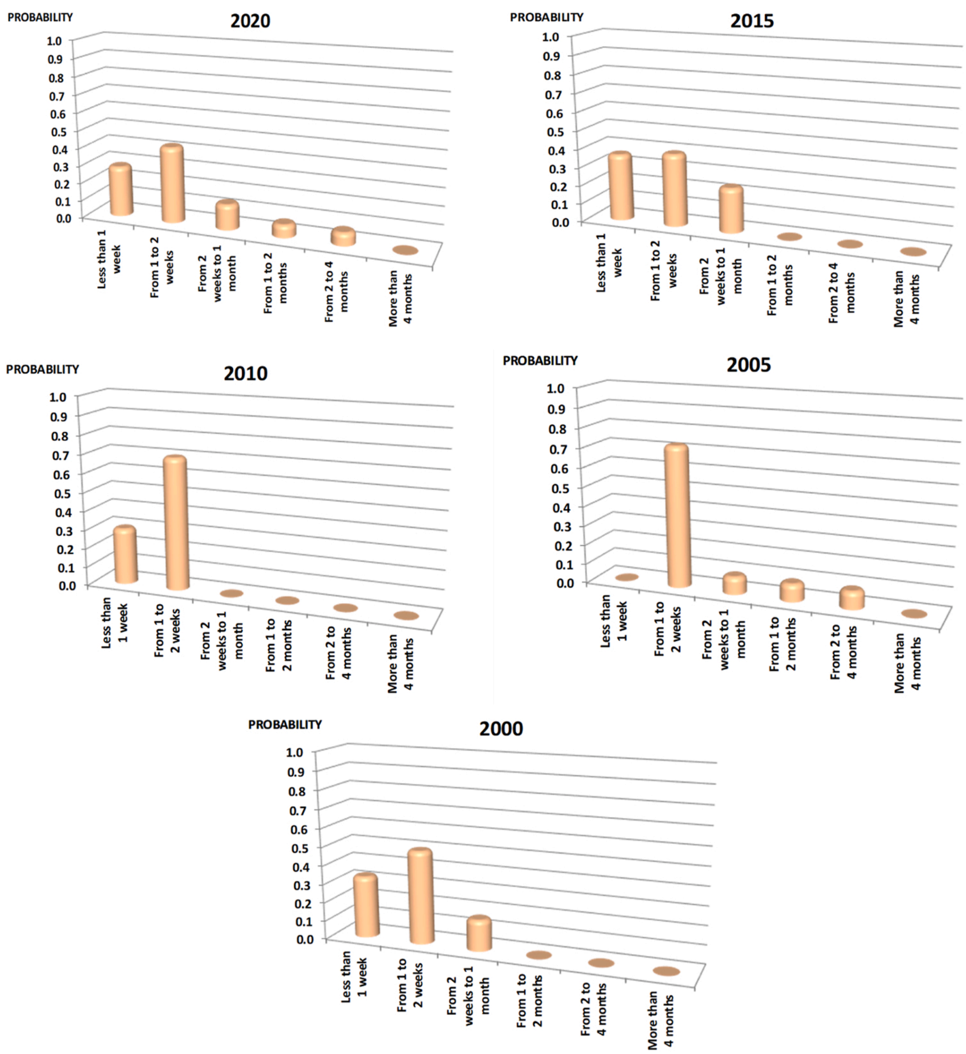

Fig. 3. Discrete probability distributions for the descriptor Time that the maintenance department would take to finish the jobs in progress and on hold or pending, for large buildings (more than 500 workers) in 2020, 2015, 2010, 2005, and 2000 (from top to bottom).

subcriterion Consulting Spanish technical journals on maintenance, in the 2000 survey. In the 2000, 2015 and 2020 surveys, the question regarding Use of the internet to search for information to solve maintenance problems is not included.

- In the 2020 survey, only the average values of some questions are provided, instead of the complete data. In these cases, the maximum probability is assigned to the scale level of this average value. This is the case of all the sub-criteria included in the criteria Annual Maintenance Cost and its distribution and Outsourced Maintenance, and of the sub-criteria Percentage of corrective maintenance carried out annually compared to preventive maintenance and Percentage of urgent work received.
- In the subcriterion Percentage of corrective maintenance carried out annually compared to preventive maintenance, until the 2010 survey, only corrective and preventive tasks were counted. As of 2015, the percentage of predictive maintenance is included. However, to maintain the ability to make comparisons over the 20-year period evaluated, the possibility of predictive maintenance will not be considered in the percentage.

As 40 descriptors per alternative are evaluated and there are 15 alternatives, it was necessary to build 600 discrete probability distribution functions. Fig. 3 shows, as an example, the discrete probability distribution function of the descriptor The time it would take the maintenance department to finish the work in progress and on hold or pending.

As an example, the utility function of descriptor Time that the maintenance department would take to finish the jobs in progress and on hold or pending, associated with the subcriterion Pending work (C_{CMA7}), $U_{C_{CMA7}}(y)$ is calculated from Eq. (7), using the data for the discrete probability functions shown in Fig. 3, and the utility vector included in Table 5. Therefore, in the case of the large buildings and the year 2015 sector, would get:

$$U_{C_{CMA7}}(y) = 1*0.3750+0.7293*0.4063+0.3919*0.2500+0.1763*0.0000+0.0543*0.0000+0.0000*0 = 0.7693 \quad (8)$$

A similar methodology is applied to the remaining sub-criteria included in the criterion Control of Maintenance Activities and efficiency (CMA), giving, once again for buildings with more than 500 workers and in 2015:

$$U_{C_{CMA1}}(y) = 1*0.9000+0.0000*0.1000 = 0.9000 \quad (9)$$

$$U_{C_{CMA2}}(y) = 1*0.6667+0.0000*0.3333 = 0.6667 \quad (10)$$

$$U_{C_{CMA3}}(y) = 1*0.1563+0.8333*0.1563+0.6666*0.2188+0.4999*0.1250+0.3332*0.0938+0.1665*0.0313+0.0000*0.0625 = 0.5313 \quad (11)$$

$$U_{C_{CMA4}}(y) = 1*0.1670+0.8571*0.1670+0.7143*0.1670+0.5714*0.1670+0.4286*0.0810+0.2857*0.0810+0.1428*0.0810+0.0000*0.0810 = 0.5943 \quad (12)$$

$$U_{C_{CMA5}}(y) = 1*0.0310+1*0.1880+0.6742*0.0940+0.4520*0.1560+0.2953*0.1560+0.1852*0.2500+0.1088*0.1250+0.0566*0.0000+0.0219*0.0000+0.0000*0 = 0.4589 \quad (13)$$

$$U_{C_{CMA6}}(y) = 1*0.2188+0.5342*0.3438+0.2549*0.3125+0.0925*0.0938+0.0000*0.0313 = 0.4908 \quad (14)$$

The weightings of the above sub-criteria are shown in Table 7 (to four places of decimals): $w_{CMA1} = 0.2874$, $w_{CMA2} = 0.2193$, w_{CMA3}

Table 9
Statistical results of simulation in Spanish buildings sector.

Alternative		Mean	SD[a]	Median	Min.	5th percentile	95th percentile	Max.
Year 2020	Small Buildings	0.6434	0.0530	0.6440	0.4636	0.5539	0.7277	0.7935
	Medium Buildings	0.6283	0.0499	0.6291	0.4474	0.5447	0.7082	0.7836
	Large Buildings	0.6534	0.0420	0.6565	0.4717	0.5797	0.7171	0.7630
Year 2015	Small Buildings	0.5880	0.0771	0.5936	0.3081	0.4527	0.7091	0.8272
	Medium Buildings	0.5976	0.0728	0.5978	0.3671	0.4756	0.7167	0.8003
	Large Buildings	0.6209	0.0729	0.6244	0.3496	0.4964	0.7347	0.8377
Year 2010	Small Buildings	0.6613	0.0556	0.6614	0.4702	0.5702	0.7508	0.8279
	Medium Buildings	0.5286	0.0662	0.5300	0.3077	0.4190	0.6373	0.7303
	Large Buildings	0.6863	0.0641	0.6891	0.4566	0.5762	0.7865	0.8615
Year 2005	Small Buildings	0.6616	0.0515	0.6613	0.4621	0.5787	0.7482	0.8726
	Medium Buildings s	0.6448	0.0506	0.6474	0.4492	0.5564	0.7230	0.7957
	Large Buildings	0.6088	0.0786	0.6064	0.3664	0.4819	0.7413	0.8478
Year 2000	Small Buildings	0.6139	0.0672	0.6165	0.3639	0.4970	0.7203	0.8202
	Medium Buildings	0.5734	0.0740	0.5700	0.3454	0.4544	0.7011	0.8474
	Large Buildings	0.6533	0.0697	0.6557	0.3951	0.5327	0.7629	0.8929

[a] Standard Deviation.

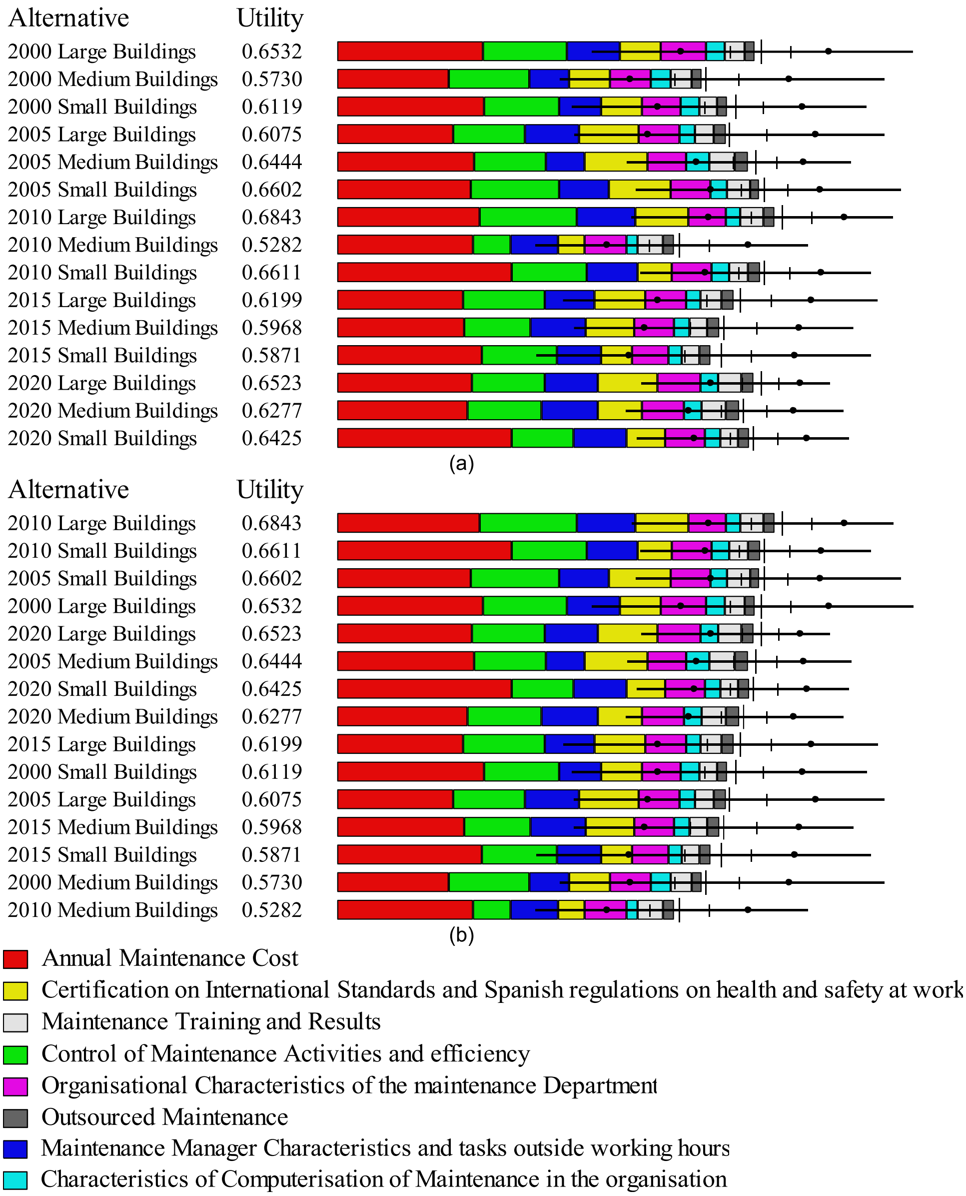

Fig. 4. Results: (**a**) by year; (**b**) by rank.

$= 0.1345$, $w_{CMA4} = 0.0852$, $w_{CMA5} = 0.0582$, $w_{CMA6} = 0.0868$ and $w_{CMA7} = 0.1285$ (one additional decimal place is considered with respect to the values shown in Table 7). The utility of the criterion CMA is:

$$\begin{aligned}\text{Utility(CMA)} &= w_{CMA1} * U_{C_{CMA1}}(y) + w_{CMA2} * U_{C_{CMA2}}(y) + w_{CMA3} * U_{C_{CMA3}}(y) + w_{CMA4} * U_{C_{CMA4}}(y) + w_{CMA5} * U_{C_{CMA5}}(y) + w_{CMA6} \\ &\quad * U_{C_{CMA6}}(y) + w_{CMA7} * U_{C_{CMA7}}(y) \\ &= \\ &= 0.2874 * 0.9000 + 0.2193 * 0.6667 + 0.1345 * 0.5313 + 0.0852 * 0.5943 + 0.0582 * 0.4589 + 0.0868 * 0.4908 + 0.1285 \\ &\quad * 0.7693 \\ &= 0.6951\end{aligned} \tag{15}$$

A similar calculation was performed for the other criteria.

Table 10
Levels of excellence according to utility.

Utility	Description	User satisfaction	Level of excellence
$[0.8, 1.0)$	High asset management utility values achieved in most criteria. High levels of safety, availability and asset efficiency achieved in the building.	Satisfaction of building users, workers and visitors.	Excellent
$[0.6, 0.8)$	Acceptable utility values in most criteria with some occasionally excellent and others with lower values. Acceptable levels of safety, availability and asset efficiency in the building.	Satisfaction of users, workers and visitors to the building, although sometimes they may be affected by some contingency that is quickly resolved.	Satisfactory
$[0.4, 0.6)$	Medium utility values in most criteria but possible deficiencies in some in particular. Low risk of a serious problem in the building due to asset management. Specific safety and availability problems, with too many activities to be solved urgently. There is a high potential for continuous improvement.	Users, workers and visitors to the building may be affected by some contingency that is solved after a certain period of time.	Acceptable
$[0.2, 0.4)$	High risk of a serious problem in the building due to asset management. Existence of occasional situations of lack of safety, in the quality in the service to be provided, and/or frequent unavailability.	Users, workers and visitors to the building will be regularly affected by some contingency which will be solved after a certain period of time	Deficient
$[0, 0.2)$	Frequent serious problems related to inefficiencies in asset management in the building. Presence of frequent situations of lack of safety, quality of services to be provided by the building and/or unavailability.	Dissatisfaction of building users, workers and visitors that causes frequent complaints.	Highly deficient

6. Results

Monte Carlo simulation was used to compute the data, incorporating uncertainty. This method uses random numbers to provide an estimate of the uncertainty of a variable that is a complex function of one or more probability distributions, which in this study is the discrete probability distribution function of each descriptor. The Monte Carlo simulation uses a random number generator to produce random samples from probability levels. Each set of samples is used to calculate the utility of a possible outcome from the uncertainties of the data point. Each calculated utility is called a trial, and after performing an appropriate number of trials or iterations until a representative statistical sample is obtained, the resulting value can be used as an estimate of the cumulative probability distribution of the desired utility.

Once the quantitative model has been created, applying fuzzy AHP produces a transfer equation. The discrete probability distributions associated with each scale level of each alternative are the independent variables that will allow the calculation of uncertainty.

The number of samples to be used depends on the complexity of the model, but a sufficiently large number of samples allows the desired parameter to be estimated with high probability and low error. In this study, different numbers of trials have been used (1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500 and 6000) with a seed of 30,000; after 5000 trials the results are unchanged.

Table 9 shows the statistical results obtained. Fig. 4 shows the results obtained incorporating uncertainty.

Fig. 4 shows that the greatest utility is achieved in large buildings in 2010, followed by small buildings in 2010 and 2005. In contrast, the last three positions are taken by small buildings in 2015, followed by medium size buildings in 2000 and 2010. The range of utilities goes from 0.5282 to 0.6843. Therefore, the general level of the buildings sector from 2000 to 2020 can be considered acceptable, although it is very far from positions of excellence and thus offers a good possibility for continuous improvement.

The results can be assessed absolutely according to their utility. The $[0, 1]$ utility interval is divided into five sub-intervals, and a level of excellence assigned to each sub-interval. This procedure was previously applied by Chen et al. [134] for the evaluation of suppliers and, in this study, it was modified to adapt it to the assessment of asset management in the buildings sector. The excellence levels defined are shown in Table 10. Medium and small size enterprises in 2015 and medium size buildings in 2000 and 2010 have utilities in the interval $[0.4, 0.6)$, which implies a low risk of a serious problem arising in the business due to inefficiencies in asset management. For example, an excessive amount of pending work can cause safety problems in the building or make it impossible to carry out any of its functions, which can be very serious in places such as hospitals or centres of education. The other alternatives have utilities in the interval $[0.6, 0.8)$, although closer to the lower value, and so, although they may be considered satisfactory, they also require significant improvements to reach the levels of excellence present in other industrial sectors, such as the automotive sector.

There is no significant trend in any of the sizes of buildings during the 20 years analysed (see Fig. 5), but utility values that remain stable over time are observed. However, it can also be seen that medium size buildings were most affected by the economic crisis that began in Spain in 2008 and lasted until 2014, and which also affected most of the developed countries. Large buildinsssgs were also affected by the crisis, but its effect on asset management has been seen since 2015, that is, once the crisis ended. However, although the SARS-CoV-2 pandemic could have negatively affected the sector, a slight improvement can in fact be seen in all sizes of buildings from 2015 to 2020. This may stem from the decrease in users in both public and private buildings due to the increase in home working, the decrease in the provision of services, or the provision of online services and the requirement for prior appointments, causing the number of users of the buildings to decrease dramatically. It was thus possible to improve the values of urgent activities or pending jobs that maintenance departments usually received. The linear prediction (or polynomial in medium buildings) for 2025 for the three building sizes shown in Fig. 5 also points to a stability in the utility value in the three building sizes.

The average variation in utility over the 20 years in small buildings shows a growth of 1.25 %, in the case of medium size buildings it was 2.52 %, and in large buildings 0.29 %. The average variation from 2000 to 2020 in the entire sector is 1.36 %. Although this value is positive, it is insufficient to cover a period of 20 years, and it seems that maintenance departments are not adapted to meeting the current needs of building users or the application of techniques in Industry 4.0.

The average evolution in Annual Maintenance Cost (AMC) in the entire sector is 2.73 % in the 20 years analysed, with the average being higher in the case of small buildings (5.07 %), followed by medium size buildings (3.44 %). However, in large buildings, improvement in costs has not been achieved, and there has been a decrease in utility of 0.31 %. There is a clear trend towards improvement in utility for the next five years in the case of small buildings, while the trend is stable in medium size buildings and shows a slight decrease in large buildings (see Fig. 6(a)). In the case of the sub-criterion Total annual maintenance costs of the company (global average variation of the sector of 8.27 %), it is small buildings that seem to be more aware (utilities close to or equal to 0.8 and an average variation of 5.37 %). Here, a better trend can be seen in the twenty years analysed than for the other sizes of buildings, although it is also evident that this cost is directly related to the size of the building. In the case of medium size buildings, the average variation of the period is very significant (an increase of 16.97 %), although the utilities of all the years analysed are very low [0.3625, 0.6800], due to the serious setback of the Spanish economic crisis. This seems to have affected this size of buildings more than others, with reductions in utility of 28.07 % and 7.99 % between 2008 and 2014. These decreases are not seen in large buildings and they appear sometime after the end of the crisis in small buildings. Regarding the sub-criterion Percentage of annual cost related to outsourcing jobs, it seems that small and medium size buildings have improved these costs, with average increases in utility in the period analysed of 25.77 % and 2.88 % respectively. Large buildings, meanwhile, show an average decrease. of 8.04 %, although it seems that work had been done on these costs during the period of economic crisis, the trend shows a significant increase in maintenance outsourcing in large and medium size buildings. This seems to be in line with the literature that points to this effect in both public and private buildings [4,33] and also with the aggregate results for all sectors of the SMA [130]. This points to a slight increase in outsourcing aimed at annual contracts, but maintained in the long term and based on stable relationships so that the subcontracted company can adapt to the specific needs of the contracting company. On the other hand, in the sub-criterion Percentage of annual cost

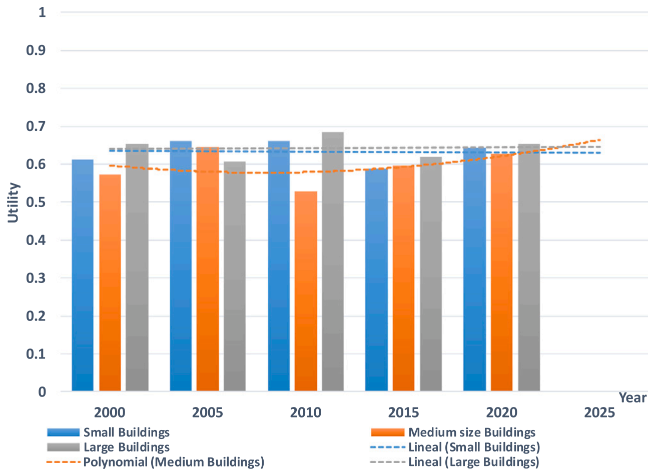

Fig. 5. Evolution of utility in all sizes of buildings from 2000 to 2020.

related to spare parts and consumables, it is the large buildings, unlike in the other cost sub-criteria, which seem to have higher utilities throughout the period analysed [0.8305, 1]. This could be due to economies of scale, discounts for volume in purchasing, greater power of the buyer or optimisation in the management of spare parts as is done in other areas of organisations: This effect even seems to show a slight improvement trend over the next five years. This trend, however, is negative in the case of small buildings. In any case, the scale level the highest probability in the buildings sector as a whole is between 0 % and 10 %, although the mean is in line with the results of the aggregate surveys for all sectors that show very stable mean values of 30 % during the period analysed.

In the criterion Certification on International Standards and compliance with Spanish regulations on health and safety at work (CIS) (see Fig. 6(b)), significant utility improvements can be seen in the sector of 18 %, and by size (4.07 % in small buildings, 14.11 % in medium buildings and 9.36 % in large buildings) in the 20-year period. Therefore, a high percentage of buildings are certified in quality or environmental management, in line with the latest results obtained by the SMA aggregated for all sectors (70 %–77 % of companies certified in ISO 9000 and 64–73 % in ISO 14000). It should be noted that the greatest useful contribution to the criterion is due to the sub-criterion related to health and safety at work, followed at some distance by the ISO 9000 certification, in all sizes of buildings and all years analysed. There is also a growing trend in certification to ISO 9000 in large buildings, although decreasing trends are shown in ISO 14000 in all sizes of buildings, which is worrying since, according to the United Nations Environment Program [135] building energy demand increased by around 4 % from 2020. This represents the largest increase in the last 10 years [136]. Additionally, CO_2 emissions from buildings operations have reached an all-time high of around 10 $GtCO_2$, an increase of some 5 % from 2020, and 2 % higher than the highest level in 2019. This is because in 2021, there was more energy-intensive use of buildings as workplaces reopened after the pandemic, although hybrid working remained. In addition, more emerging economies increased their use of fossil fuel gases in buildings.

The average variation in utility of the criterion Control of Maintenance Activities and efficiency (CMA) in the sector over the 20 years is 0.40 %, and was best in medium size buildings (increase of 5.60 %), while the variation is negative in small buildings (−3.06 %) and large buildings (−1.33 %). In addition, the linear trend shown in Fig. 6(b)) for the coming years is decreasing in all sizes of buildings, which considering the importance of this criterion can be assessed as concerning. The sub-criterion Percentage of corrective maintenance carried out annually compared to preventive maintenance has experienced an increase in utility in the sector and period of 9.05 %, with greater improvements in small buildings with an average utility increase of 21.40 %, followed by medium size buildings at 4.09 % and large buildings at 1.68 %. This increase in utility translates into a decrease in the percentage of corrective maintenance applied as opposed to preventive. Thus, for example, in 2020 preventive reached 57 % in small buildings, 54 % in medium size buildings and 43 % in large buildings, the industry average being 51 %. Therefore, it seems that small buildings have a higher percentage of preventive (along with predictive) than medium size and large buildings. This behaviour can also be seen in the global results of the SMA (2020) for all sectors, in which there is a preponderance of preventive over corrective since 2012, standing at 56 % in 2015 and 51.65 % in 2020 (although in both cases predictive maintenance is included with preventive). However, this value is still far from the 60 % considered necessary, and even further from only undertaking 10 % residual or minimum corrective. This tendency towards an increase in preventive is expected to be maintained according to the linear prediction made for the next five years in small and medium size buildings. In the sub-criterion Percentage of urgent work received, the average variation of the sector in the 20 years is favourable with an improvement in utility of 4.34 %, which comes from medium size buildings where the average variation is 21.44 %, while in small and large buildings the evolution is negative (−8.18 % and −0.24 % respectively). The trend is positive for this sub-criterion for 2025 in medium size buildings, but negative in the other building sizes. In 2020, the average percentage of the sector is 21 %, 23 % in small buildings, 9 % in medium size and 27 % in large buildings. Comparing the previous results with the aggregate for all sectors, which stands at 26.40 %, the buildings sector shows a slightly better performance, especially in the case of medium size buildings. With respect to the sub-criterion Pending work, the average utility variation of the sector in the twenty years analysed is −5.09 %, (−8.23, −0.59 % and −6.44 % in small, medium and large buildings respectively). There is a negative trend in

Fig. 6. Evolution of utility in all sizes of buildings from 2000 to 2020 by criteria: (a) Annual Maintenance Cost (AMC); (b) Certification on International Standards and compliance with Spanish regulations on health and safety at work (CIS); (c) Control of Maintenance Activities and efficiency (CMA); (d) Maintenance Manager Characteristics and maintenance tasks outside working hours (MMC); (e) Organizational Characteristics of the maintenance Department (OCD); (f) Characteristics of Computerization of Maintenance in the organization (CCM); (g) Outsourced Maintenance (OMA); (h) Maintenance Training and Results (MTR).

this criterion for all building sizes by 2025. 57 % of buildings have less than a month of work pending (a very poor result when compared to 80 %, 90 % and 81 % of companies that have a workload of less than one month according aggregate values by sectors in the latest surveys (2010, 2015 and 2020). Therefore, it seems that workforce reductions in buildings are even higher than those experienced by other companies, and that the trend will continue to increase, thus increasing the pending workload.

The average utility variation of the criterion Maintenance Manager Characteristics and maintenance tasks outside working hours (MMC) over the 20 years is 4.40 %, and is also positive by building size (5.14 %, 7.50 % and 0.56 % from smaller to larger). The linear trend represented in Fig. 6(d)) for the coming years is increasing in small and medium buildings and is stable in large buildings. Experience as a maintenance manager is a relevant factor in buildings, with an average of 16.5 years in the buildings sector in 2020 (the highest value compared to other sectors), which means that maintenance managers are sought with extensive experience in this field. If the special requirements of buildings such as hospitals or educational centers are taken into account, this result is understandable. Thus, a growing trend can be seen in this sub-criterion, 71.98 % of those surveyed had more than 8 years experience in 2015, and in 2020 this value is 81.71 %. In addition, it can be seen that as the size of the building increases, so does the experience, and the trend is also increasing with respect to said size. Therefore, this position is filled by managers with more and more years of experience, although undoubtedly the economic crisis followed by the pandemic has affected this mater, causing the supply of positions to decrease and the desire to assume fewer risks in the face of changes in employment, adding to the already limited mobility of personnel in Spain up to now. In any case, it should be noted how little importance is assigned to the maintenance manager in Spanish companies.

The most likely academic qualifications of maintenance managers in the buildings sector are industrial engineer followed by industrial technical engineer (qualifications similar to those in the aggregate results for other sectors). Utility during the 20 years analysed has improved notably in small and large buildings and the prediction of the trend in this sub-criterion is for an increase in the next five years in all sizes of buildings. This degree (currently eliminated in Spain), due to the very varied skills it included, such as technical knowledge (mechanics, hydraulics, pneumatics, automation, etc., that is, related to machines and facilities) but also management, project control and economics, it considered optimal to carry out the functions of the head of maintenance. This is despite the fact that most universities that offered this degree did not include specific maintenance subjects. This meant, and it still does today, (with degrees in mechanical, electrical and electronic engineering and a master's degree in industrial engineering or other specific master's degrees) that maintenance managers had to be specifically trained in asset management during the performance of their duties in the building, especially in matters of management, control and, currently, aspects related to electronics, automation and digitisation. Therefore, it is important to assess this sub-criterion in a complementary way along with those related to: Attendance at

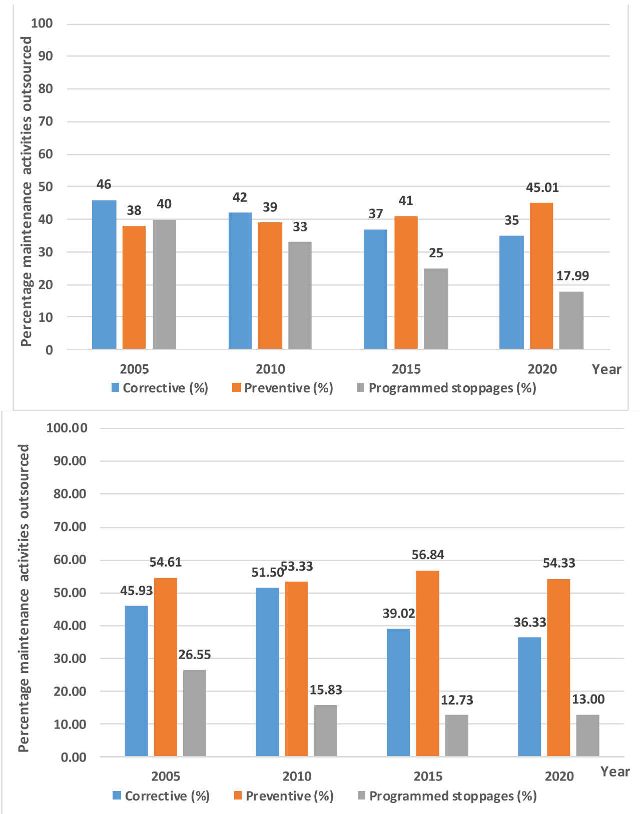

Fig. 7. Evolution in the percentage of general outsourced activities (left) and for the buildings sector (right). * No data is provided for the year 2000 because the survey did not ask these questions.

conferences, talks, seminars, etc. on maintenance, Consulting Spanish technical journals on maintenance and Use of the internet to search for information to solve maintenance problems. In the case of Attendance at conferences, talks, seminars, a utility variation in the period analysed in the sector of 6.71 % is found, with positive values in medium and large Buildings, but negative in small buildings, which can be attributed to the lower financial resources available. Similar behaviour can be seen in Consulting Spanish technical journals on maintenance, with an average utility variation of 6.85 % over the 20-year period.

The criterion Organisational Characteristics of the maintenance Department shows an average variation over the 20-year period of 0.11 %, with positive variations in small (0.33 %) and medium (0.45 %) buildings, but negative in large buildings (−0.46 %). The prediction shows roughly constant utilities by 2025 (see Fig. 6(e)). The utility variation of the period in the sub-criterion Hierarchical dependency of the maintenance department is 7.87 %, which seems to assign greater importance to maintenance departments, as they are increasingly dependent directly on the management of the building and not on other areas or departments of the building.

Table 11
Results of the sensitivity analysis.

Criterion	Variation in utility	
	-5 %	+5 %
Annual Maintenance Cost (AMC)	No change in the classification of alternatives	No change in the classification of alternatives
Certification on International Standards and Spanish regulations on health and safety at work (CIS)	Medium buildings (2005) 6ª ->7ª Small buildings (2020) 7ª ->6ª	Small buildings (2010) 2ª ->3ª Small buildings (2005) 3ª ->2ª Large buildings (2000) 4ª ->5ª Large buildings (2020) 5ª ->4ª
Control of Maintenance Activities and efficiency (CMA)	Large buildings (2000) 4ª ->5ª Large buildings (2020) 5ª ->4ª	Small buildings (2010) 2ª ->3ª Small buildings (2005) 3ª ->2ª
Maintenance Manager Characteristics and tasks outside working hours (MMC)	No change in the classification of alternatives	No change in the classification of alternatives
Organisational Characteristics of the maintenance Department (OCD)	No change in the classification of alternatives	No change in the classification of alternatives
Characteristics of Computerisation of Maintenance in the organisation (CCM)	No change in the classification of alternatives	No change in the classification of alternatives
Outsourced Maintenance (OMA)	No change in the classification of alternatives	No change in the classification of alternatives
Maintenance Training and Results (MTR)	No change in the classification of alternatives	No change in the classification of alternatives

Regarding the human resources of the maintenance department, the utility variation of the sector in the period is 12.99 %, but while in medium and large buildings it is positive (25.17 % and 16.74 %) in small buildings it is negative (- 2.94 %). This sub-criterion shows strongly the influence of the economic crisis in medium and large buildings, which seems to have been overcome since 2015; On the other hand, small buildings show a downward trend that has in practical terms not recovered after the economic crisis. Therefore, maintenance departments have continued to hold the limited number of resources with which they had been operating during the economic crisis. The utility variation of the sector in Existence of organisation to resolve incidents outside working hours over the 20 years is 1.31 %, with 1.53 %, 3.19 % and −0.75 % in small, medium and large buildings respectively. A decreasing utility trend can be seen in the three sizes of buildings, which predicts worse behaviour for 2025. This sub-criterion has a higher probability, considering all the sectors, which has evolved from 48 % setting up maintenance staff shifts in the year 2000 and 45 % in 2005 to the establishment of a duty system with 43 %, 45 % and 46 % in 2010, 2015 and 2020 respectively. In the buildings sector, the greater likelihood has gone from a duty system in 2000 (29.04 %) to shifts in maintenance personnel in 2005 and 2010 (32.93 % and 36.36 %) and in 2015 and 2020 the more likely form in the other sectors, that is, duty systems (30.47 % and 54 % respectively) have been adopted. The cooperation of the production staff in maintenance activities shows negative global variations in the sector, also with decreasing predictions for 2025. In fact, the highest probability in all building sizes and throughout the 20 years evaluated corresponds to no cooperation. The percentage of respondents who indicate no collaboration in all sectors has grown slightly in recent years (33 % in 2015 and 36 % in 2020), in the case of the buildings sector as well (54.28 % in 2015 and 58.71 % in 2020). In addition, it can be seen that this lack of cooperation is much higher in the buildings sector than in the other sectors, probably due to the specifics of the buildings sector, which in many cases requires highly specialised workers in health, education, catering or administration, with a complete lack of training and knowledge about maintenance, machines and facilities. These percentages are also higher in small buildings. The application of TPM, which gives such good results in the automotive industry, however, has zero values in small and medium buildings and insignificant values in large buildings (1.59 % in 2015 and 3.17 % in 2020). Therefore, in this area there are many opportunities for improvement in the coming years, especially in medium and large buildings.

With respect to the computerisation of maintenance, the average utility variation of the sector over the 20 years is 0.16 %, with medium size buildings showing the best evolution (4.43 %). There is also an increasing future trend for the next five years in large and medium size buildings, with a polynomial prediction of order 2. In addition, there is a decrease in utility in the previous sizes of buildings during the economic recession and, a beginning of the recovery from 2015, although without reaching the levels of the year 2000. The sub-criterion that contributes the most to the overall usefulness of the criterion is Level of satisfaction in the application of computerisation. Its average variation of the sector is −1.13 %, where −6.68 %, 5.94 % and −2.68 % are the utility variations in small, medium and large buildings respectively. The most probable value is acceptable or meeting the objectives of the sector as a whole, as well as for the different sizes of building. Therefore, although this level of satisfaction is suitable for the departments, there is still room for improvement until better than expected results are achieved. In addition, it seems once again that this level of satisfaction dropped substantially in medium and large buildings during the recession, and the recovery began in 2015. However, in small buildings, the level of satisfaction, which also dropped during the recession, is recovering much more slowly than in the other building sizes, and is the only size in which the results are unsatisfactory in 2020. This may be due to the greater economic resources available to the medium and large buildings, which can acquire new systems for maintenance management, mainly modules included within Enterprise Resource Planning (ERP) that ensure integration with the rest of the company's data and are equipped with new analysis tools to facilitate decision making. Therefore, it seems that small buildings are operating with CMMS or other older systems that are less adapted to the new maintenance needs. The use of computer systems is mainly applied to work order management (around 20 %), preventive maintenance (approximately 18 %) and planning (14 %) and, to a lesser extent, to create technical records (13 %) and machine inventories (11 %). It should be noted that the use of computer systems for cost control or stock management is insufficient (10 % and 6 % respectively), although recently they have been higher in large buildings than in other building sizes. There is no substantial increase in the computerisation of machine monitoring in recent years due, for example, to an increase in predictive maintenance, but rather percentages of 5–6 % are being maintained with respect to other possible activities to be computerised by the sector.

The utility variation in the criterion Outsourced Maintenance (OMA) in the sector between 2000 and 2020 is 3.95 %, with growth in all sizes of buildings and a predicted linear trend that is also increasing for 2025 (see Fig. 6(g)). The annual percentages of corrective maintenance and out-sourced scheduled stoppage also have positive utility variations for the sector throughout the period (11.78 % and 13.50 % respectively) and suggest increasing trends for 2025 in all sizes of buildings (although in the specific case of the percentage of outsourced corrective in large companies it seems that it will hold to a more constant level). In any case, the sub-criterion relating to corrective maintenance seems to show a decrease during the beginning of the recession in small and medium-sized buildings that gradually recovered. Using specific data instead of utility, it can be seen in Fig. 7 that the aggregate evolution of all sectors shows a decrease in corrective and outsourced scheduled shutdowns and an increase in outsourced preventive in the 20 years analysed. Scheduled shutdowns are a common practice in companies, taking advantage of the holiday period to carry out all maintenance in bloc, a practice that has been decreasing during the period analysed. In the buildings sector, the percentage of scheduled shutdowns has historically been lower than in other sectors, as it is a more common practice in processing plants than in buildings. The percentage of outsourced preventive remains approximately constant throughout the period, while outsourced corrective has been decreasing in the last ten years. The utility variation in Quality of work outsourced is 5.39 %, also increasing in all building sizes and, in addition, there is a growing utility trend for this sub-criterion in large and medium size buildings and a constant value in small buildings. This seems to show an increasing effort by outsourcing companies to satisfy the needs of customers. In fact, in 2020, 46.47 % of those surveyed rated outsourced maintenance as good, and 51.92 % as acceptable; By building size, it seems that the rating improves slightly with building size, with 36.36 % rating good in small, 50 % in medium and 53.33 % in large buildings.

The utility of the criterion Maintenance Training and Results (MTR) shows the evolution in Fig. 6(h) with a positive variation of 3.00 % for the entire sector from 2000 to 2020. Similar results are obtained in all sizes of buildings in the period analysed (0.83 %, 4.40 % and 3.56 %), although the improvement is greater in larger buildings. However, although the trend for 2025 is seen to be growing in large buildings, the same is not true of other sizes of buildings. The training received improved overall by 2.44 % in the period studied, getting better as the size of the building increases, until reaching a utility increase of 5.28 % in large buildings; In this size of building, a prediction of a growing trend for 2025 can also be seen. It is in small buildings where the effect of the economic crisis is most apparent, and it has not been able to improve once the crisis was over, while it been overcome in medium buildings, which have improved their utility in 2020. This matter caused the greatest concern in companies until 2010, when it was replaced by the limitation of resources in 2015, and in 2020, both issues jointly cause the most concern, although the low digitisation of the maintenance area is also worrying. The average age of buildings has experienced constant growth from 16.68 years in 2000, to 21.21 years in 2020, probably due to the long economic crisis that did not favour renovation and, moreover, has not allowed the incorporation of new technologies. In addition, the pandemic has contributed to increasing the aging of buildings, especially in large buildings (32.26 % of buildings were between 16 and 25 years old in 2015, and in 2020 this percentage had risen to 43.48 %, while buildings over 25 years old went from 32.26 % in 2015 to 39.13 % in 2020). All this means that when renovation is possible, with the consequent improvements in digitisation of assets, advanced training of staff in maintenance will be required in line with the new digital skills demanded by Industry 4.0. Regarding the sub-criterion Versatility of human resources, a utility variation of 3.00 % is also observed in the sector, although now the variations by building size are 3.87 %, 2.18 % and 2.97 % in small, medium and large buildings. The noticeable improvement of small buildings with respect to other sizes of buildings may be due to the fact that they have fewer maintenance staff and therefore need more versatility. The trends for 2025 are clearly growing in the three sizes of buildings, a very positive thing, since versatility facilitates the organisation and scheduling of maintenance, thereby increasing the performance of the workforce, especially when resources are limited.

6.1. Sensitivity analysis

To check the robustness of the model, a sensitivity analysis was carried out, modifying the weightings of the criteria by $\pm$ 5 % and updating the weightings of the rest of the criteria proportionally. The results can be seen in Table 11. Although the alternatives show very small differences in utilities, there are only two criteria in which there is any change in the classification of alternatives, and in no case does it affect the alternative in first place. In addition, the changes imply only a permutation between two alternatives that occupy correlative positions. Considering that there could be 210 permutations between pairs of alternatives in total, and only 5 have appeared, that is, 2.38 %, the model can be considered robust.

7. Conclusions

This study describes a fuzzy MCDM model that allows the evolution of asset management to be assessed from the year 2000–2020. This model, unlike the literature, allows the incorporation of the uncertainty, ambiguity, and inaccuracies typical of decision-making processes in complex real word problems. In addition, instead of using average values of a sector or a country, it uses all the data for the behaviour of the sector, thereby improving the accuracy of the results. The model has been applied to the buildings sector, particularised for three sizes of buildings: small, medium and large, according to the definition of company size provided by the EU, and over a period of twenty years. For the construction of the model, the judgements of four specific experts in buildings asset management were used. The model integrates different MCDM techniques such as fuzzy AHP, using the geometric mean method suggested by Buckley, to avoid the problems of other methodologies, as well as Multi-Attribute Utility Theory, to obtain utilities by sub-criterion and alternative, with discrete probability distribution functions. A Monte Carlo Simulation is applied using 5000 trials to estimate the final uncertainty of the model.

The results of the model show that the best performance is associated with large buildings in 2010, followed by small buildings in 2010 and 2005. This seems to show that the period of economic crisis that began in Spain in 2008 and lasted until 2014 seriously affected asset management, as it seems that the utility levels at the beginning of the crisis in small and large buildings have not yet been regained. However, the situation is worse in medium buildings, which had the worst utilities before and at the start of the crisis and, although they have been slowly recovering since then, even in 2020 their utilities were below those of small and large buildings.

[0.5282, 0.6843] is the range of utilities of all the alternatives analysed. Medium buildings (2000, 2010, 2015) and small buildings (2015) have utilities of less than 0.6, which is why they are associated with a low risk of a serious problem in the building due to asset management, with the presence of occasional safety and availability problems, and having too many activities to solve urgently. Therefore, there is also a high potential for continuous improvement. The other alternatives that have utilities greater than 0.6 are at a satisfactory level of excellence, with adequate levels of safety, availability, and asset efficiency in the building, but since they have utilities closer to 0.6 than the upper limit of the range (0.8) there is still great potential for improvement, especially in adapting to the new needs of industry 4.0 and of users.

The average utility variation in the sector in the 20 years analysed is 1.36 % and, as the size of the building increases, it is 1.25 %, 2.52 % and 0.29 %. These variations, although positive, are insufficient for a period of 20 years. There is also no significant trend for utility prediction in 2025, so all building sizes will approximately maintain their utility.

Therefore, it seems that maintenance departments continue to use traditional procedures, technologies and techniques, showing reluctance to adopt new technologies, techniques and optimisation models that have worked efficiently in companies for some time, such as mobile technologies in the work of the maintenance management. or TPM. For example, in this study it has been found that TPM is not used at all in small and medium buildings, and only insignificantly in large buildings, despite the excellent results that it has traditionally provided in the automotive sector. Furthermore, small buildings seem to be using CMMSs or other old systems that are not adapted to the new maintenance needs; In this sense, the study carried out by Accruent [137] shows that the use of the traditional procedure for carrying out work orders obtained on paper from a CMMS, requires a work order closing time of about 7 days, which could be reduced to 2 days with the right technology and on-site review and completion of work orders. In any case, the use of computer systems for cost control or stock management is still insufficient in buildings; this causes delayed work orders due to lack of stock and/or inaccurate and disorganised stock databases; Additionally, there been no substantial increase in the computerisation of facilities monitoring in recent years, due, for example, to an increase in predictive maintenance. In addition, although the SARS-CoV-2 pandemic has improved the development of remote activities and digital transformation processes in a large number of activities in organisations, it seems that this effect is not significantly appreciable in the 2020 survey data of the SMA on asset management in buildings.

The fundamental problem, however, is that maintenance departments in general, and buildings in particular, rarely occupy important positions in decision making about technological or other types of upgrade. In fact, 60.71 %, 50.00 % and 56.52 % of small, medium and large Spanish buildings did not even have a maintenance policy within the company policy in 2020, or did not answer the question (indicative of ignorance, which makes us suspect the non-existence of said policy).

Despite all of the above, total annual maintenance costs of buildings have improved during the 20 years analysed, although it is small buildings that seem to be more conscious of this, and it is also evident that this cost is directly related to building size. In addition, the building sector has achieved an increase in the percentage of preventive as opposed to corrective maintenance, reaching values of 57 %, 54 % and 43 % in 2020 in small, medium and large buildings respectively. Also, the Percentage of urgent work received from the sector in 2020 is 21 %, a better value than the 26.40 % found on average for all sectors. The quality of outsourced work has improved substantially in the sector and in all building sizes, which seems to confirm the increasing effort of outsourcing companies to satisfy the needs of customers. In fact, in 2020, 98.39 % of those surveyed rated outsourced maintenance as good or acceptable. The training received improved globally by 2.44 % in the period analysed, getting better as the size of the building increases. The academic qualifications of maintenance managers in the buildings sector are most likely to be industrial engineer, followed by industrial technical engineer, qualifications that, although suitable for performing the role of maintenance manager, also require additional specific training in asset management to carry out of their duties in the building. This is especially true in matters of management, control, and currently, aspects related to electronics, automation and digitisation.

The trends in asset management in the short term focus on the need to:

- Improve education and training, adopt more intuitive digital systems, and use them to improve training, as well as integrate traditional knowledge with that coming from the new digital native human resources.
- Focus on the key and differentiating activities, eliminating those that do not add value. Use outsourcing in activities that do not generate value.
- Make decisions based on data and its analysis.
- Eliminate resistance to change and share knowledge to achieve a business culture adapted to continuous change.
- Obtain comprehensive and reliable data.
- Replace the corrective policy with preventive and predictive maintenance, directing asset maintenance towards proactive management using data and predictive technologies.
- Use CMMSs to optimise spending, digitalisation of all maintenance processes, management of asset engineering documents, and IoT control for real-time communication between devices.

Although the adoption of new technologies presents great opportunities for improvement, they can also, if not fully and properly implemented, lead to a waste of resources and low yields.

Among the limitations of the research are that some surveys do not provide data for some specific sub-criteria, so it has been necessary to use constant discrete distribution functions for all levels of the indicator scale, thereby increasing the uncertainty of the results. In addition, although the surveys carried out by SMA make it possible to access a greater quantity and quality of data, as they are superior to most of the studies used in the literature, a still greater quantity of data in the building sector would allow a more representative result for the building sector by building size to be obtained.

As future lines of work, it is intended to include in the model some matters introduced into the latest 2020 survey, on facilities management, digitisation and reliability and maintenance, provided that they can be related to the level of excellence of asset management and meet the conditions required by a criterion. For example, it would be of great value to assess whether there is a maintenance policy within the company policy, or the maintenance department has developed a strategic program for maintenance improvement, for example related to Reliability Centered Maintenance (RCM) or Life Cycle Cost (LCC). Also analysing whether there are sustainability actions within the department or the level of digitisation of the asset management activities carried out would serve to evaluate new skills more adapted to the current needs and requirements of the industry and its users.

CRediT authorship contribution statement

María Carmen Carnero: Conceptualization, Methodology, Investigation, Formal analysis, Writing – Original Draft, Writing – Review & Editing, Funding acquisition. **Aurora Martínez-Corral:** Formal analysis, Writing – Review & Editing, Supervision, Project administration. **Javier Cárcel-Carrasco:** Formal analysis, Writing – Review & Editing, Supervision, Project administration.

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.

Data availability

Data will be made available on request.

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