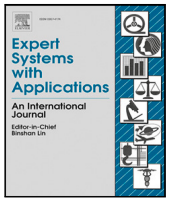
Expert Systems With Applications 221 (2023) 119724

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa



A state-of-the-art survey of evaluation based on distance from average solution (EDAS): Developments and applications

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ARTICLE INFO

Keywords:
EDAS
Multiple criteria decision making (MCDM)
Decision making
Fuzzy sets
Uncertain decision making

ABSTRACT

Evaluation based on distance from average solution (EDAS), developed in 2015, is one of the well-known and frequently utilized methods which is applied for different types of decision making problems. The output of EDAS is a ranking order of alternatives based on their aggregated distance scores. In this regard, the literature lacks a comprehensive literature review on the developments and applications of EDAS. For this purpose, this study conducts a comprehensive literature review on developments, extensions, and applications of the EDAS method. First, the EDAS method and its well-known extensions are shortly introduced. Next, a theoretical literature review of studies is presented. A meta analysis is performed in terms of publication year, authors, authors' countries, journals, and combined methods, uncertainty sets. Practical problems of the EDAS are categorized into nine application groups as agriculture, business management, construction management, energy and natural resources, healthcare management, information technology (IT), manufacturing, supply chain management, and transportation management. Results of this study can empower real-life decision makers to handle vague and incomplete information involved in decision process, and express opinions of different stakeholders in different applications under novel extensions of the EDAS.

1. Introduction

Multi Criteria Decision Making (MCDM) methods, also known as Multi Attribute Decision Making (MADM) and Multi Criteria Decision Analysis (MCDA), are considered as straightforward but very reliable decision making tools to address complex and multi-aspect real-world problems (Filatovas, Marcozzi, Mostarda, & Paulavičius, 2022; Garg, Görçün, Kundu, & Küçükönder, 2023; Hosseini, Paydar, & Hajiaghaei-Keshteli, 2021; Savkovic, Jovancic, Djenadic, Tanasijevic, & Miletic, 2022). MCDM approaches enable decision makers to comparatively evaluate several decision alternatives with respect to infinite number of decision criteria, and select the alternative which acquire highest score considering the criteria. Generally, MCDM approaches are developed to address two important issues in decision making problems; first, calculating importance of decision criteria, and comparatively prioritize or rank a set of alternatives with respect to the criteria. Development of MCDM approaches have been an important point in management science and other fields. MCDM approaches have attracted high attention to be applied in various decision making problems in different fields such as energy planning (Alizadeh, Soltanisehat, Lund, & Zamanisabzi, 2020; Deveci, Cali, Kucuksari, & Erdogan, 2020), healthcare management (Mardani, Saraji, Mishra, & Rani, 2020; Stević, Pamučar, Puška, & Chatterjee, 2020; Yazdani, Chatterjee, & Torkayesh, 2020), tourism industry (Büyüközkan, Mukul, & Kongar, 2020; Lin, 2020; Lin, Li, Jiang, Yu, & Wei, 2020), construction management (Chand, Thakkar, & Ghosh, 2020; Mahdiyar, Mohandes, Durdyev, Tabatabaee, & Ismail, 2020), defence industry (Muravev & Mijic, 2020; Pamučar, Petrović, & Ćirović, 2018), marketing (Jain, Darbari, Kaul, & Jha, 2020; Mahdiraji, Zavadskas, Kazeminia, & Abbasi Kamardi, 2019), waste management (Karagoz, Deveci, Simic, Aydin, & Bolukbas, 2020; Mishra, Rani, et al., 2020; Torkayesh, Tavana, & Santos-Arteaga, 2022; Torkayesh, Zolfani, Kahvand, & Khazaelpour, 2021; Wang & Wang, 2022), transportation systems management (Pamucar, Deveci, Canıtez, & Bozanic, 2020; Samanta & Jana, 2019), humanitarian and disaster management (Sarma, Das, Dutta, & Bera, 2020).

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https://doi.org/10.1016/j.eswa.2023.119724
Received 2 June 2022; Received in revised form 12 November 2022; Accepted 19 February 2023
Available online 23 February 2023

Today in the literature, there are different tools and techniques for MCDM that differ in mathematical formulation and complexity. A common feature shared in all MCDM is the normalization of input data in the initial matrix and their aggregation into a single criterion function to generate a final score. MCDM methods use different units of measure to represent attributes in the initial matrix. Therefore, before applying aggregation functions, it is necessary to standardize the information. The standardization of information that presents the attributes is done using normalization techniques (Pamučar, Žižović, Biswas, & Božanić, 2021). Normalization techniques are used to standardize heterogeneous criteria whether it is a qualitative or quantitative, and benefit or cost. After normalization of the elements of the matrix, aggregation operators are used for the fusion of standardized information (Ali, Mahmood, Ullah, & Khan, 2021). Information aggregation operators aim to define a unique criterion value on the basis of which the dominance and ranking of alternatives from the considered set are defined.

In recent decades, several MCDM methods have been developed to enhance the decision making capability for real-world decision makers in real practices. Some of well-known and frequently used methods are analytic hierarchy process (AHP) (Saaty, 1989), the technique for order of preference by similarity to ideal solution (TOPSIS) (Hwang & Yoon, 1981), VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic, 1998), ELimination and Choice Expressing REality (ELECTRE) (Roy, 1990), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Brans & Mareschal, 1990), Complex Proportional Assessment (COPRAS) (Zavadskas, Kaklauskas, & Sarka, 1994), Weighted Aggregated Sum–Product Assessment (WASPAS) (Zavadskas, Turskis, Antucheviciene, & Zakarevicius, 2012), evaluation based on distance from average solution (EDAS) (Keshavarz Ghorabaee, Zavadskas, Olfat, & Turskis, 2015), Combined Compromise Solution (CoCoSo) (Yazdani, Zarate, Zavadskas, & Turskis, 2019), Best Worst Method (BWM) (Rezaei, 2015), simultaneous evaluation of criteria and alternatives (SECA) (Keshavarz-Ghorabaee, Amiri, Zavadskas, Turskis, & Antucheviciene, 2018), determination of objective weights using a new method based on the removal effects of criteria (MEREC) (Keshavarz-Ghorabaee, Amiri, Zavadskas, Turskis, & Antucheviciene, 2021), additive ratio assessment (ARAS) (Zavadskas & Turskis, 2010), analytic network process (ANP) (Saaty, 2004), combinative distance-based assessment (CODAS) (Keshavarz Ghorabaee, Zavadskas, Turskis, & Antucheviciene, 2016), Multi-Objective Optimization on the basis of a Ratio Analysis (MULTIMOORA) (Brauers & Zavadskas, 2010), and Measurement of alternatives and ranking according to COmpromise solution (MARCOS) (Stević et al., 2020). High range of the developed MCDM methods are due to the requirements of professional and strategic decision making in real-world practices. EDAS is one of the recently developed methods with high applicability in various complicated decision making problems. Considering its applicability and performance, EDAS has turned to be one of the popular and frequently used method. However, no literature review is conducted on the EDAS so far. Therefore, a literature review is needed to be conducted in order to identify and highlight recent important studies, developments, and applications related to EDAS method. Thus, this study aim to identify several trends regarding utilization of EDAS in terms of publication date, case study, authors contributing to the fields, journals publishing in the field. Second focus of this study is based on highlighting recent developments of the EDAS under different uncertain environments as well as integration of EDAS with other MCDM methods. Finally, a detailed review is conducted on classification of studies based on their applications in various industries and fields. Contributions and goals of this study are summarized as follows:

- A comprehensive literature review is conducted and a meta analysis is performed based on the collected publications in terms of time trend, locations, first-authors, journals, combined methods, and uncertainty sets.
- Classification of the studies into nine different categories: agriculture, business management, construction management, energy and natural sources, healthcare management, IT and technology, manufacturing, supply chain management, and transportation management. Classification of the studies would show how well EDAS is performing in a specific field of decision making.
- Finally, a discussion is presented to highlight the issues and challenges as well as important implications for future directions.

The rest of this paper is structured as follows. Section 2 presents the traditional form of EDAS method and then its important extensions. Section 3 presents the research methodology for the literature review. Section 4 reviews studies used EDAS in terms of various metrics. Different applications of EDAS studies are categorized and discussed in Section 5. Section 6 present the discussions, and highlight findings of this review, limitations, and future research directions.

2. EDAS & its extensions

For the first time in the literature of MCDM methods, Keshavarz Ghorabaee et al. (2015) developed EDAS method, as a ranking method to tackle complicated decision making problems where number of alternatives should be prioritized with respect to multiple criteria. Compared to other methods, one of the major differences of EDAS is reflected in its normalization process. Unlike traditional methods such as TOPSIS and VIKOR which are designed to determine best alternative according to ideal and anti-ideal solutions, in real-life decision making problems lower distance to ideal solution and higher distance to anti-ideal solution would not guarantee to get the most suitable solution. Therefore, EDAS aims to determine the best alternative according to average solution based normalization technique. To determine the score of each alternative and determine their relative ranking order, EDAS utilizes two measures, named PDA (positive distance from average value), and NDA (negative distance from average value). For a complicated and multi-aspect MCDM problem with n criteria and m alternatives, EDAS can be applied according to the following steps.

Step 1- Initial decision matrix is constructed based on real data or a qualitative scale by participants (decision makers or expert). For a decision making problem with n criteria ($n = 1, 2, \ldots, j$) and m alternative ($m = 1, 2, \ldots, i$), initial decision matrix is as follows.

$$\begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1m} \\ x_{21} & x_{22} & \ldots & x_{2m} \\ . & . & \ldots & . \\ . & . & \ldots & . \\ . & . & \ldots & . \\ x_{n1} & x_{n2} & \ldots & x_{nm} \end{bmatrix} \quad (1)$$

Step 2- In normalization, average solution is determined considering all criteria. Average solution of each criterion j is calculated as Eq. (2).

$$AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \quad (2)$$

Step 3- Two important measures of the EDAS, PDA and NDA are calculated based on nature of conflicting criteria as follows. For a beneficial criterion, PDA and NDA values are derived using Eqs. (3)–(4), and for cost criterion, PDA and NDA values are determined according to Eqs. (5)–(6).

$$PDA_{ij} = \frac{max(0, x_{ij} - AV_j)}{AV_j} \quad (3)$$

$$NDA_{ij} = \frac{max(0, AV_j - x_{ij})}{AV_j} \quad (4)$$

$$PDA_{ij} = \frac{max(0, AV_j - x_{ij})}{AV_j} \quad (5)$$

$$NDA_{ij} = \frac{max(0, x_{ij} - AV_j)}{AV_j} \tag{6}$$

Step 4- Weight coefficient of each criteria (w_j) assigned by experts or other methods are used to determine weighted sum of PDA and NDA values according to Eqs. (7)–(8).

$$SP_i = \sum_j^n w_j PDA_{ij} \tag{7}$$

$$SN_i = \sum_j^n w_j NDA_{ij} \tag{8}$$

Step 5- Weighted sum values of PDA and NDA are normalized using Eqs. (9)–(10).

$$NSP_i = \frac{SP_i}{max_i(SP_i)} \tag{9}$$

$$NSN_i = 1 - \frac{SN_i}{max_i(SN_i)} \tag{10}$$

Step 6- Finally, compromise score of each alternative is determined using Eq. (11). Alternatives are ranked by their compromise score from higher values to lower values where alternative with higher score is considered as the best alternative.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{11}$$

After development of the EDAS, several studies attempted to enhance the reliability and capability of this method by implementing different uncertainty set to efficiently tackle real-life complex problems (with qualitative data) (Fan, Cheng, & Wu, 2019; Panchal, Singh, Chatterjee, Zavadskas, & Keshavarz-Ghorabaee, 2019; Wang, Wang, & Wei, 2019; Yazdani, Torkayesh, Santibanez-Gonzalez, & Otaghsara, 2020). Next year in 2016, Keshavarz Ghorabaee, Zavadskas, Amiri, and Turskis (2016) developed an extended version of EDAS under type-1 fuzzy set using trapezoidal fuzzy numbers to address a supplier selection problem under uncertain conditions. Type-1 fuzzy sets, triangular fuzzy numbers and trapezoidal fuzzy numbers, based EDAS have been used over and over to tackle different problems related to energy management, healthcare management, manufacturing, construction management, many other applications (Ecer, 2018; Keshavarz Ghorabaee, Amiri, Zavadskas, & Turskis, 2017; Kundakcı, 2019; Ren & Toniolo, 2018). To address the issues in type-1 fuzzy sets, Kahraman et al. (2017) developed a new version of EDAS based on intuitionistic fuzzy set to tackle location selection of solid waste disposals through an advanced fuzzy set. In next attempts, more advanced form of EDAS were developed under different uncertainty sets such as hesitant fuzzy set (Kutlu Gündoğdu, Kahraman, & Civan, 2018; Mi & Liao, 2019), and interval type-2 fuzzy set (Li, Wang, & Wang, 2019; Zhang, Wei, Gao, Wei, & Wei, 2019). Interval numbers like grey numbers (Hasheminasab, Gholipour, Kharrazi, Streimikiene, & Hashemkhani, 2020; Stanujkic, Zavadskas, Keshavarz Ghorabaee, & Turskis, 2017) and rough numbers (Stević, Pamučar, Vasiljević, Stojić, & Korica, 2017; Zhan, Jiang, & Yao, 2020), neutrosophic sets (Li, Wang, & Wang, 2019; Supciller & Toprak, 2020; Xu, Cui, & Xian, 2020) are other popular uncertainty sets used for the EDAS in recent years. To consider probabilistic nature of decision making environment in some real-life cases, probabilistic set (He et al., 2019; Keshavarz Ghorabaee, Amiri, Zavadskas, Turskis, & Antucheviciene, 2017a; Shrivathsan et al., 2020) are very recent new developments used to enhance capability of the EDAS. Most recently, Keshavarz-Ghorabaee (2021) proposed a simple modification to EDAS under two exceptional cases.

3. Research methodology

To conduct a comprehensive literature review, scientific databases such as Web of Science, and Scopus as well as well-known publishers such as ScienceDirect, SpringerLink, and IEEE Xplore were used. In the review process, keywords such as "EDAS", "EDAS MCDM", "Fuzzy EDAS", "Grey EDAS", "Integrated EDAS" and "Neutrosophic EDAS" were used as search terms. In the first step of the review process, the authors reached 201 publications. After the duplicate elimination process, the number of publications decreased to 189. Afterwards, abstract screening is completed and the number of publications in the total record decreased to 150. Finally, detailed full-text screening is completed and the total number of publications reviewed in this study decreased to 146. The detailed steps of the research methodology of this study are summarized in Fig. 1.

In the review process, non-English publications, irrelevant publications which are not related to the EDAS and publications where the EDAS is used only for sensitivity analysis were excluded. On the other hand, publications which have EDAS on the main topic, studies which have EDAS as the only MCDM method and publications which have the EDAS method as an integrated MCDM approach were included in the search procedure.

4. Literature survey

MCDM techniques have attracted many researchers due to their simplicity and practicality to transfer the views of the experts to complicated case studies. At this point, EDAS is one of the most preferred MCDM techniques recently in the literature, since it has been proposed in 2015.

The first EDAS publication in the literature was performed by Keshavarz Ghorabaee et al. (2015). It was used for a multi-criteria inventory classification (MCIC) problem as an alternative to ABC analysis. Stević, Tanackov, Vasiljević, and Vesković (2016) used the combined AHP-EDAS method to rank scenarios of city logistics in the city of Doboj. Turskis and Juodagalvienė (2016) presented a hybrid MCDM approach for a stair shape selection problem. Keshavarz Ghorabaee, Zavadskas, Amiri, and Turskis (2016) provided a supplier selection application of the fuzzy EDAS method. As the first EDAS method was published in 2015 for an inventory classification problem, the first combination of the EDAS method was proposed in 2016 for a city logistics evaluation problem. Furthermore, the first EDAS method under uncertainty was performed via a fuzzy approach in 2016 to deal with a supplier selection problem.

In 2017, Keshavarz Ghorabaee, Amiri, Zavadskas, and Turskis (2017) presented the first interval type-2 fuzzy (IT2F) extension of the EDAS method and the method was performed for a subcontractor evaluation in construction projects. Keshavarz Ghorabaee, Amiri, Zavadskas, Turskis, and Antucheviciene (2017b) also proposed a discrete stochastic-based EDAS approach for the performance evaluation of bank branches. Apart from fuzzy and stochastic-based approaches, Stanujkic et al. (2017) presented the interval grey numbers-based EDAS method and its application to a contractor evaluation case study. Different from type-1 and ITF2 fuzzy extensions, Kahraman et al. (2017) used the first interval-valued intuitionistic fuzzy EDAS method for a solid waste site selection problem. Keshavarz Ghorabaee, Amiri, Olfat, and Khatami Firouzabadi (2017) developed a fuzzy multi-product multi-period multi-objective model for a reverse logistics network design problem. The authors used the fuzzy EDAS method to determine greenness scores in the mathematical model. Different from Stanujkic et al. (2017), Peng and Liu (2017) proposed a grey system theory-based novel single-valued neutrosophic soft set (SVNSS) methods via EDAS approach for a software development project selection problem. Furthermore, Peng, Dai, and Yuan (2017) presented another interval-valued fuzzy number (IVFN) based approach as a Multi-Attributive Border Approximation Area Comparison (MABAC), EDAS and similarity

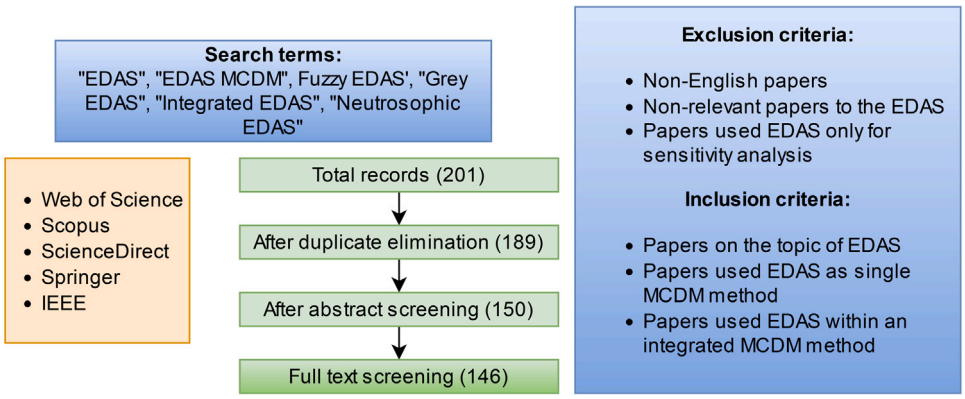

Fig. 1. Article search procedure.

measure methods and these methods are applied to numerical examples. Zavadskas, Cavallaro, Podvezko, Ubarte, and Kaklauskas (2017) assessed principles of sustainable development in a healthy and safe built environment via various MCDM methods including EDAS. The authors proposed Vilnius as a case city. Stević et al. (2017) used a hybrid decision-making trial and evaluation laboratory (DEMATEL) and Rough EDAS methods for a supplier selection problem in a construction project. In this study, DEMATEL was combined with EDAS for the first time in the literature. Furthermore, Keshavarz Ghorabaee et al. (2017a) also proposed a probabilistic simulation-based hybrid MCDM approach including TOPSIS, CODAS, WASPAS and EDAS methods for evaluating the service quality of various airlines. Karaşan and Kahraman (2017) proposed an interval-valued neutrosophic-based EDAS approach and this approach is applied to a supplier selection case study. Juodagalvienė, Turskis, Šaparauskas, and Endriukaitytė (2017) evaluated the shape plan of houses with an integrated EDAS-SWARA method. As the first EDAS method in the literature dealing with uncertain environments was published in 2016, there is a significant increase in the quantity of uncertainty-based EDAS publications in 2017. Apart from fuzzy approaches, other types of uncertainty-based approaches like probabilistic-based, grey-based, interval-value-based and neutrosophic-based EDAS methods were proposed by the researchers. Furthermore, there is a significant increase in the scope of case studies in 2017. For instance, EDAS was utilized to deal with a waste management case study for the first time in 2017 (e.g. Kahraman et al. (2017)). Meanwhile, new hybrid variations of EDAS were proposed by the authors (e.g. EDAS-DEMATEL, EDAS-SWARA, EDAS-MABAC, and vice versa).

Valipour, Sarvari, and Tamošaitiene (2018) investigated the accuracy of step-wise weight assessment ratio analysis (SWARA), complex proportional assessment (COPRAS), fuzzy analytic network process (FANP), fuzzy analytic hierarchy process (FAHP), a fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS), simple additive weighting (SAW) and evaluation based on distance from average solution (EDAS) approaches. These techniques were applied to Iranian highway public–private partnership (PPP) projects. Čereška, Zavadskas, Bucinskas, Podvezko, and Sutinys (2018) applied several MCDM methods for steel wire rope diagnostic research. The authors applied Entropy, Criterion Impact Loss (CILOS) and Aggregate ObjectiveWeights (IDOCRIW) methods for weighting the criteria and applied TOPSIS, COPRAS and EDAS methods for the alternative selection process. Afterwards, Feng, Wei, and Liu (2018) proposed a hesitant fuzzy linguistic term (EHFLTS) extension of the EDAS method for project management criteria evaluation. In the meantime, Keshavarz Ghorabaee, Amiri, Zavadskas, and Antucheviciene (2018) proposed a fuzzy extension of hybrid Step-wise Weight Assessment Ratio Analysis (SWARA), CRiteria Importance Through Intercriteria Correlation (CRITIC) and EDAS method and this method was applied to a construction equipment evaluation case study in Iran. Similarly, Keshavarz Ghorabaee, Amiri, Zavadskas, Turskis, and Antucheviciene (2018b) proposed a fuzzy EDAS method for subcontractor evaluation. Keshavarz Ghorabaee, Amiri, Zavadskas, Turskis, and Antucheviciene (2018a) presented an analysis of the rank reversal (RR) phenomenon and it is integrated into EDAS and TOPSIS methods. As a different application of EDAS, Karaşan and Kahraman (2018) presented a novel interval-valued based neutrosophic EDAS approach for prioritizing United Nations (UN) sustainable development goals for Turkey. Mathew and Sahu (2018) applied various MCDM techniques e.g. CODAS, EDAS, weighted aggregated sum product assessment (WASPAS) and multi-objective optimization based on ratio analysis (MOORA) methods for conveyors and automated guided vehicles (AGVs) selection problem. Palevičius, Podviezko, Sivilevičius, and Prentkovskis (2018) evaluated Lithuanian cities regarding their infrastructure for electric vehicles via EDAS, SAW, TOPSIS, and PROMETHEE II approaches. Chen et al. (2018) applied EDAS and WASPAS with normalization (WASPAS-N) methods for the facility location selection problem of a teahouse in Lithuania. Aggarwal, Choudhary, and Mehrotra (2018) used EDAS approach to evaluate smartphones in the Indian market. Karabaševic, Zavadskas, Stanujkic, Popovic, and Brzakovic (2018) implemented SWARA-EDAS combination to a personnel selection process in the IT sector. Kutlu Gündoğdu et al. (2018) published a hesitant fuzzy EDAS study and the method was applied to a hospital selection problem for organ transplantation. Ren and Toniolo (2018) utilized DEMATEL and EDAS in an interval decision-making process of hydrogen pathways ranking problem. Chatterjee, Banerjee, Mondal, Boral, and Chakarborty (2018) proposed Design of Experiments (DOE)-EDAS method in a material selection problem. Ecer (2018) integrated fuzzy-AHP and EDAS methods in a third-party logistics provider evaluation problem. Feng et al. (2018) employed a hesitant fuzzy extension of the EDAS method to an illustration example of a project evaluation problem. Liang, Zhao, and Luo (2018) evaluated the cleaner production of gold mines with a picture fuzzy EDAS-ELECTRE method. Pehlivan, Şahin, Zavadskas, and Turskis (2018) compared various MCDM methods in a fuzzy environment, including fuzzy EDAS in the evaluation of organizational strategy development problems. Stević, Vasiljević, Zavadskas, Sremac, and Turskis (2018) evaluated carpenter manufacturers with the fuzzy EDAS method. In 2018, there is a reasonable increase in the quantity of MCDM publications including the EDAS method. Moreover, there is a dramatic increase in the quantity of EDAS-based publications dealing with uncertain case studies. On the other hand, there is remarkable progress in the variety of case studies. As an example, the EDAS method is used for the evaluation of international organizations' policies (e.g. UN) for the first time in the literature (Karaşan & Kahraman, 2018).

A linear increase in EDAS-based publications in the literature is observed in 2019. Fan, Li, and Wu (2019) applied EDAS on the cross-efficiency evaluation method for the robot selection process. Additionally, Fan, Cheng, and Wu (2019) proposed an interval-valued complex

fuzzy soft information environment-based EDAS multi-criteria group decision-making (MCGDM) approach to rank the economic policies of provinces. As a different fuzzy approach, Li, Ju, et al. (2019) developed a picture fuzzy multi-attribute group decision-making (MAGDM) approach and used the EDAS method for the emergency alternative selection process. Moreover, Li, Wang, and Wang (2019) used a linguistic neutrosophic EDAS method for the property management company selection problem in China. He et al. (2019) offered an integrated model of probabilistic uncertain linguistic sets (PULTSs) based EDAS approach to MAGDM process of green supplier selection. The results of the rankings were compared with the probabilistic uncertain linguistic TOPSIS method (PUL-TOPSIS method) and probabilistic uncertain linguistic weighted average (PULWA) operator. Hasheminasab, Hashemkhani Zolfani, Bitarafan, Chatterjee, and Abhaji Ezabadi (2019) applied a two-stage MCDM process to assess the materials used in building facades. In the first stage, the fuzzy Delphi method was applied to find the most critical criteria and in the second stage, EDAS was applied to measure experts' ideas. As a novel extension of EDAS, Zavadskas, Stevic, Turskis, and Tomaševic (2019) developed the Minkowski space extension of the EDAS method (EDAS-M) in the autonomous vehicle selection process. The authors used CRITIC method to weigh the criteria. Adalı and Tuş (2019) applied the EDAS method for a facility location selection of a private hospital. The authors used CRITIC method to determine the weights of the criteria. Mathew and Thomas (2019) presented an interval-valued EDAS method for a flexible manufacturing system selection. As a different application of the picture-fuzzy-based EDAS approach, Zhang, Gao, Wei, Wei, and Wei (2019) applied the picture 2-tuple linguistic numbers-based EDAS method to a green supplier selection problem. Further to that, Zhang, Wei, et al. (2019) also presented a picture fuzzy EDAS approach for the green supplier selection problem. Peng (2019) compared various intuitionistic fuzzy soft set (IFSS) based MCDM methods and applied them to case studies from the literature. Kharazi, Yazdani, and Khazealpour (2019) employed AHP-TOPSIS-EDAS methods in determining the underground dam locations in Iran. As a unique EDAS-based hybrid method, Kundakcı (2019) proposed a MACBETH-EDAS-based MCDM approach for a steam boiler evaluation problem in the textile industry. Mi and Liao (2019) developed a hesitant fuzzy BWM-based EDAS approach and it was applied to a case study of commercial endowment insurance products evaluation. Schitea et al. (2019) employed intuitionistic fuzzy WASPAS, COPRAS and EDAS methods in a hydrogen mobility roll-up site selection case study. Tadić, Krstić, and Brnjac (2019) combined fuzzy EDAS and AR DEA (Assurance Region Data Envelopment Analysis) methods and the combination are applied to an inland intermodal terminals selection problem. Wang et al. (2019) assessed the safety of a construction project via the 2-tuple linguistic neutrosophic information-based EDAS method. Zhang, Wei, Gao, Wei, and Wei (2019) evaluated renewable micro-generation technologies via probabilistic EDAS-WASPAS approaches and the Monte Carlo simulation is implemented to deal with the robustness of the results. Kaviani, Yazdi, Ocampo, and Kusi-Sarpong (2019) presented a supplier selection problem in the oil and gas industry with the grey-EDAS method. As a financial application of EDAS method, Ouenniche, Perez, and Ettouhami (2019) proposed EDAS based non-parametric classifier and it was used to predict the bankruptcy of various firms in the UK. Qian, Liu, and Fang (2019) published a grey risky multi-attribute decision-making (RMADM) method and its EDAS application for a case study of investment evaluation. Stević et al. (2019) evaluated suppliers for more than ten production areas with fuzzy-AHP and fuzzy EDAS-based hybrid methods. Yazdani, Gonzalez, and Chatterjee (2019) evaluated the impacts of disasters on the supply chain of agriculture and its effects on the circular economy with a SWARA and EDAS-based MCDM method. Further, Yazdani, Chatterjee, Pamucar, and Abad (2019) published a case study of the green supplier selection process of a construction company in Spain with FMEA, DEMATEL and EDAS methods. Although the EDAS method is used for various case studies in 2019, most of the publications deal with supply chain, construction and facility location selection problems. Furthermore, there is a significant increase in the quantity of picture fuzzy EDAS applications in the literature. Moreover, the 2-tuple linguistic neutrosophic information-based, various intuitionistic fuzzy and Minkowski space-based EDAS studies are presented by the researchers distinctly in 2019.

In 2020, there is a dramatic increase in the number of publications dealing with MCDM cases with the EDAS method. Dhanalakshmi, Madhu, Karthick, Mathew, and Kumar (2020) performed a fuzzy TOPSIS-EDAS method for biomass material evaluation. The weights of the criteria were evaluated via the FAHP method. As a review study, Siksnelyte-Butkiene, Zavadskas, and Streimikiene (2020) presented a comprehensive literature review that highlights MCDM methods used in the evaluation of renewable energy technologies in households. Tolga and Basar (2020) proposed a fuzzy EDAS approach for hydroponic system evaluation in urban farming. Nevertheless, Xu et al. (2020) proposed a single-valued complex neutrosophic extension of the EDAS method and they applied it to a green supplier selection problem. As a different case study, Shrivathsan et al. (2020) published a case study of test case prioritization in the IT sector via the probabilistic linguistic information-based EDAS method. Mitra (2020) proposed EDAS method in jute fibre evaluation in India. No, Niroomand, Didehkhani, and Mahmoodirad (2020) applied the interval EDAS method to rank bank branches in Iran. Özmen and Aydoğan (2020) proposed a linear BWM (best-worst method) based EDAS method for logistics centre location problems in Turkey. As a different fuzzy extension of EDAS, Ren, Hu, Yu, and Cheng (2020) used an extension of the EDAS method under a four-branch fuzzy environment for a credit evaluation problem for micro and small entrepreneurs. Polat and Bayhan (2020) employed a fuzzy EDAS approach for heating, ventilating and air conditioning (HVAC) and air handling unit (AHU) system and its supplier selection problem in a real-life case study in Russia. Skvarciany, Jurevičienė, and Volskytė (2020) carried out EDAS and hierarchical cluster analysis (HCA) methods to assess the level of sustainable socio-economic development of the European Union (EU) countries. Liang (2020) evaluated green building energy-saving design projects via the IFSs-based EDAS method. After all, Tan et al. (2020) proposed a refined single-valued neutrosophic set (RSVNSs)-based EDAS method for typhoon disaster assessment in China. Tanwar, Mehrotra, and Nagpal (2020) employed the EDAS method to evaluate the security level of network technology. As another study in the banking sector, Ozcalici and Bumin (2020) applied various MCDM techniques including EDAS for a performance measurement process of the Turkish banking sector. Abdel-Basset, Gamal, Chakrabortty, and Ryan (2020) proposed a neutrosophic environment-based hybrid MCDM approach including AHP, EDAS and COPRAS methods to evaluate the sustainability of hydrogen production options. Ali, Chiu, Aghaloo, Nahian, and Ma (2020) proposed a hybrid MCDM model, using The Integrated Determination of Objective CRIteria Weights (IDOCRIW), Best Worst Method (BWM) and EDAS for prioritizing power generation technologies in Bangladesh. Asante, He, Adjei, and Asante (2020) integrated Multi-Objective Optimization based on Ratio Analysis (MULTIMOORA) with the EDAS method to evaluate the barriers to renewable energy adoption in Ghana. As another study in the energy sector, Balali and Valipour (2020) applied the BWM-EDAS combination to optimize the energy consumption of health centres. Balezentis, Chen, Galnaityte, and Namiotko (2020) assessed the cropping sustainability at the aggregate (country) level via SAW, TOPSIS and EDAS-based hybrid approach. Behzad, Zolfani, Pamucar, and Behzad (2020) proposed a comparative study to evaluate solid waste management performances of the Nordic countries by an integrated BWM-EDAS method. As a different fuzzy EDAS method, Darko and Liang (2020) published a novel EDAS-based approach to deal with q-rung orthopaedic fuzzy multiple attribute group decision-making (q-ROFMAGDM) problems. Ghafari, Kaviani, Sedaghathoor, and Allahyari (2020) employed TOPSIS-CODAS-ARAS and EDAS-based multi-attribute decision-making (MADM) methods to

evaluate existing and recommended plant species in Iran. Hasheminasab et al. (2020) integrated grey-WASPAS, fuzzy EDAS and CODAS methods to evaluate the petroleum refinery projects. Karatop, Taşkan, Adar, and Kubat (2020) used a fuzzy AHP-EDAS-FMEA method in the renewable energy investment evaluation problem of Turkey. Madhu, Dhanalakshmi, and Mathew (2020) evaluated biomass materials concerning bio-oil yield efficiency via fuzzy-AHP, TOPSIS, VIKOR, EDAS and PROMETHEE-II techniques. Mishra, Mardani, Rani, and Zavadskas (2020) presented a novel intuitionistic fuzzy EDAS method for a healthcare waste management problem. Mostafaeipour, Dehshiri, Dehshiri, and Jahangiri (2020) applied a SWARA-EDAS-based MCDM method to evaluate potential locations for harnessing wind energy to produce hydrogen in Afghanistan. Srivastava et al. (2020) utilized the fuzzy EDAS method for an IT tool evaluation problem. Supciller and Toprak (2020) proposed a single-valued neutrosophic numbers-based SWARA-TOPSIS-EDAS method for a wind turbine evaluation problem in Turkey. Zhan et al. (2020) combined a covering-based variable precision fuzzy rough set (CVPFRS) model with PROMETHEE and EDAS methods and it is applied to various MADM problems. Zhang, Ju, Gonzalez, and Wang (2020) employed a social network analysis (SNA) based AHP-EDAS method in a construction equipment selection problem under uncertainty. Dahooie, Dehshiri, Banaitis, and Binkytė-Vėlienė (2020) evaluated cost reduction solutions in supply chain problems via grey-SWARA and grey-EDAS approaches. Fan, Jia, and Wu (2020) combined single-valued triangular neutrosophic sets and EDAS approaches and the authors applied the hybrid model to an investment evaluation case study. As a different type of neutrosophic-based approach, Han and Wei (2020) provided a multi-valued neutrosophic sets extension of the EDAS method and its illustrative application to an investment project evaluation problem. He et al. (2020) published a study of the Pythagorean 2-tuple linguistic information-based EDAS method and its application to a construction safety problem. Li et al. (2020) proposed a q-rung orthopair fuzzy sets (q-ROFSs) based EDAS method and the authors provided its application to a refrigerator evaluation problem. Finally, Yazdani, Chatterjee, and Torkayesh (2020) provided a combination of DEMATEL, BWM and EDAS methods for a supplier evaluation problem of a hospital in Spain. As the number of publications in the literature increased dramatically in 2020, researchers dealt with various types of MCDM cases by EDAS method. However, most of the case studies cope with construction management, energy management, waste management and supply chain management problems. Furthermore, there is a significant increase in the number of the EDAS publications applied under uncertainty. Most of the authors preferred to use various types of fuzzy approaches (e.g. q-rung orthopair fuzzy, intuitionistic fuzzy etc.). On the other hand, the number of studies that deal with MCDM problems by using grey-based EDAS approaches increased simultaneously.

In 2021, Karatop, Taşkan, Adar, and Kubat (2021) proposed a fuzzy-AHP, EDAS and fuzzy-FMEA-based decision-making model for a renewable energy investment problem in Turkey. Similarly, Demirtas, Derindag, Zarali, Ocal, and Aslan (2021) questioned the efficiencies of renewable energy sources via the fuzzy-based EDAS method. Differently, Chinram, Hussain, Mahmood, and Ali (2021) proposed intuitionistic fuzzy rough aggregation operators based EDAS method for a small hydropower plant location selection problem. In the scope of energy and natural resources management, Poongavanam, Sivalingam, Prabakaran, Salman, and Kim (2021) used TOPSIS, EDAS and MOORA methods to evaluate low global warming potential refrigerants for automobile air conditioning. The authors compared and analysed the results of three MCDM methods. As zero-carbon is one of the hottest topics in the world, Krishankumar, Pamucar, Deveci, and Ravichandran (2021) proposed a double hierarchy fuzzy-based EDAS method for prioritizing zero-carbon measurements for sustainable urban mobility. Differently, Balali and Valipour (2021) combined BWM and EDAS methods for prioritizing passive measures for energy optimization designing in hospitals and health centres in Iran. Almutairi, Dehshiri, Dehshiri, Mostafaeipour, Issakhov, and Techato (2021) published a case study to evaluate the potential wind energy locations in Afghanistan. The authors used the combined EDAS-SWATA method using the Weibull probability distribution function. Furthermore, Almutairi, Dehshiri, Dehshiri, Mostafaeipour, Jahangiri, and Techato (2021) proposed another MCDM approach for the wind energy location selection problem in Iran. The authors combined EDAS-SWARA-MLE methods using the Weibull probability distribution function. In the context of location selection for wind-powered hydrogen energy facility, Mostafaeipour et al. (2021) proposed a hybrid EDAS, BWM, WASPAS, ARAS, WSM based method and the authors applied their methodology to a case study in Uzbekistan. In the meantime, Abdel-Basset, Gamal, Chakrabortty, and Ryan (2021) focused on the sustainability evaluation of bioenergy production technologies in Egypt with a trapezoidal neutrosophic numbers-based hybrid EDAS-DEMATEL method. Another location selection problem for energy plants was performed by Vishnupriyan, Arumugam, Kumar, Chopra, and Partheeban (2021). The authors used the fuzzy-based TOPSIS method for a location selection case of a desalination plant in India and the authors compared the results with EDAS and BWM approaches.

Apart from the energy applications, Hou, Wang, Zhang, Wang, and Li (2021) investigated the safety risk factors of metro construction in China. The authors preferred to perform the EDAS method to identify the critical risk factors. Another EDAS implementation to a construction management case study was presented by Yahya, Naeem, Abdullah, Qiyas, and Aamir (2021). The authors introduced a novel intuitionistic fuzzy rough Frank EDAS (IFRF-EDAS) based EDAS approach for MCGDM and supported the superiority of their novel approach with a comparative construction management case study in Pakistan. As an example of another fuzzy rough sets-based approach, Ye, Zhan, and Xu (2021) proposed an intuitionistic fuzzy rough sets-based hybrid MADM approach. The authors combined PROMETHEE II and EDAS methods for a hypothetical building shape selection problem. Matić et al. (2021) evaluated asphalt production plants via an internal rough-based PIPRECIA-EDAS approach. As an example of IT and technology implementations, Ashraf, Rehman, Hussain, AlSalman, and Gumaei (2021) used a hybrid q-rung orthopair fuzzy rough set (q-ROFRS) and rough set (RS) based EDAS method for the MCGDM process of Agri Farming in robotics. Similarly, Rashid, Ali, and Chu (2021) proposed a combined EDAS-VIKOR-BWM methodology for a robot selection problem. Pramanik, Biswas, Pal, Marinković, and Choudhury (2021) performed a comparative EDAS-ARAS-MABAC-COPRAS-MARCOS method in a mobile crowd computing resource selection problem.

In terms of healthcare management applications of the EDAS method, Batool, Abosuliman, Abdullah, and Ashraf (2021) proposed a pythagorean probabilistic hesitant fuzzy-based EDAS approach in the emergency decision-making (EmDM) process of drug selection in clinical analysis. In the meantime, Özçelik and Nalkıran (2021) introduced the trapezoidal bipolar fuzzy-based EDAS method for a medical device selection problem. Kumar et al. (2021) proposed a combined EDAS-WSM-WPM-WASPAS-TOPSIS-EWM method for a knee implant femoral component selection problem. As the first Fermatean fuzzy-based EDAS study in 2021, Mishra, Rani, and Pandey (2021) used a hybrid CRITIC-EDAS methodology for a third-party logistics provider selection problem. Another EDAS study was presented by Wei, Wei, and Guo (2021) on a green supplier selection problem. The authors used a probabilistic linguistic term set (PLTS) environment to deal with the uncertainties. As another example of an uncertain environment supply chain management problem, U-Dominic, Orji, Okwu, et al. (2021) proposed an intuitionistic fuzzy-based hybrid EDAS-DEMATEL method to prioritize barriers in implementing reverse logistics policies in the Nigerian industry.

As an example of a business management application, Ren, Hu, Yu, and Cheng (2021) presented a financial case study of EDAS. The authors utilized a four-branch fuzzy set (FBFS)-based EDAS method for credit evaluation of small and micro-entrepreneurs (SMEs). No et al.

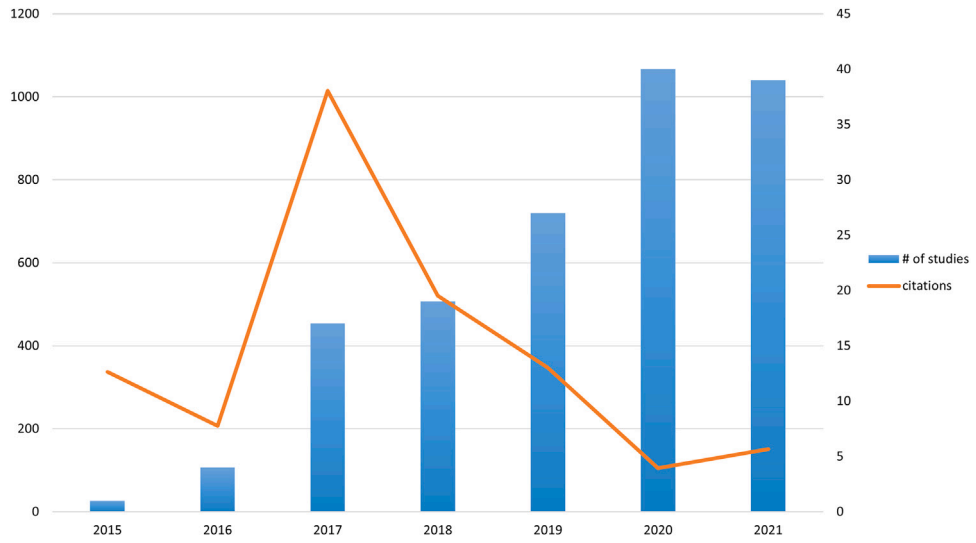

Fig. 2. Annual publications & citations.

(2020) proposed an interval EDAS method for evaluating branches of Iranian banks regarding economic criteria. Apart from No et al. another bank branch evaluation study was published by Huang, Lin, and Chen (2021). The authors proposed an enhancement EDAS method based on prospect theory. Apart from the banking sector, Mehdiabadi, Wanke, Khorshid, Spulbar, and Birau (2021) focused on the tourism sector and the authors proposed a fuzzy-based hybrid DELPHI-SWARA-EDAS method to evaluate the satisfaction of the residents regarding the tourism developments in Iran. As another case study from Iran, Hashemkhani Zolfani, Ebadi Torkayesh, Ecer, Turskis, and Šaparauskas (2021) proposed a hybrid EDAS-MABA method for an international market analysis problem. Bączkiewicz, Kizielewicz, Shekhovtsov, Wątróbski, and Sałabun (2021) used MCDM for a customer decision support tool and the authors proposed a hybrid TOPSIS-COMET, COCOSO, EDAS, MAIRCA, and MABAC approach.

In the context of manufacturing applications, Radwan, Elstohy, and Hanna (2021) proposed another hybrid MCDM method (EDAS-BWM) for a location selection case of a plastic manufacturing facility in Egypt. Panchal, Chatterjee, Pamucar, and Yazdani (2021) proposed a fuzzy lambda–tau based combined EDAS-FMEA-CODAS approach for performance evaluation of ash handling unit in a manufacturing environment. Similarly, Chairman et al. (2021) used Taguchi and EDAS methods for a material performance evaluation problem. As another study in the context of material evaluation in a manufacturing environment, Shinde, Öktem, Kalita, Chakraborty, and Gao (2021) combined EDAS-TOPSIS-VIKOR-MOORA methods to find the optimal process parameters of friction materials. One of the very first studies in the scope of transportation management was published by Srivastava, Zhang, Eachempati, and Lyu (2021). The authors used a fuzzy-based combined AHP-TOPSIS-EDAS- Interpretive Ranking Process (IRP) method to find the feasible transportation mode in India.

The first review publication was presented by Rakshit, Chatterjee, and Naskar (2021) in 2021. The authors reviewed and critically analysed the MCDM methodologies, including EDAS, in wastewater treatment cases. The critical analysis of the studies published in 2021 exhibits that the majority of the authors used the EDAS method in uncertain environments (e.a. intuitionistic fuzzy set, orthopair fuzzy rough set, pythagorean probabilistic hesitant fuzzy etc.). Furthermore, there is a significant increase in the diversity of the case studies dealing with decision-making processes.

4.1. Time trend

The number of studies published between 2015 and 2021 is shown in Fig. 2. It highlights that there is a linear increase in the number of publications over the years. According to Fig. 2, the most dramatic increases compared to the previous years in the number of publications are in 2020 and 2021 compared to the early years. Furthermore, Fig. 2 depicts that 2020 is the most productive year regarding the number of publications that use the EDAS. This dramatic increase in the number of publications indicates that the popularity of the EDAS has been increasing rapidly and the EDAS has a crucial impact on MCDM studies in the literature. Although, there is a negligible fall in the number of publications in 2021, number of publications are still following an acceptable trend.

4.2. Location trend

The geographical distribution of corresponding authors of the publications is illustrated in Fig. 3. It finds out that most of the corresponding authors are from the Far East, the Middle East and Eastern Europe. Furthermore, the Middle East is the most productive region in the world regarding the distribution of the corresponding authors.

Table 1 examines the geographical distribution of the publications provided by Fig. 3 closely. It highlights that most of the corresponding authors reviewed in this study have an affiliation with an institution in Iran. The corresponding authors from Iran constitute 13.0% of the case studies in the literature. Turkey, China, and Lithuania are the second, third, and fourth countries that compose 9.4% and 4.3% of the case studies that used EDAS as the MCDM approach in the literature respectively. On the other hand, corresponding authors from the US and Uzbekistan are located at the end of the list.

4.3. Author distribution

Table 2 provides the frequency of the reviewed publications regarding the first authors, the number of studies published by the first authors and the number of citations achieved by each first author. Keshavarz Ghorabaee et al. are located at the top of the chart by far. Authors have been cited 1047 times and they have published 12 publications in total. Stevic et al. Zhang et al. and Yazdani et al. are the second and third authors regarding the number of studies they have published. The fact remains that Peng and Liu, and Kahraman et al. are the third and the fourth most-cited authors in the literature as the numbers of their citations are 139 and 124.

Apart from Table 2, blue 3 highlights geographical distribution and the number of achieved citations of the corresponding authors. Iran, China and Lithuania are at the top of the country distribution list. The number of citations from Iran, China and Lithuania has reached

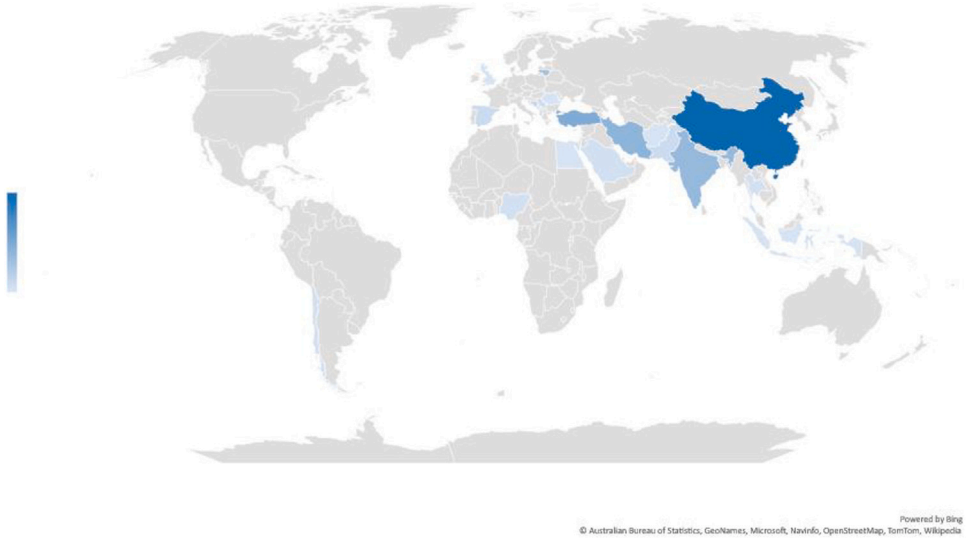

Fig. 3. Distribution of corresponding authors.

Table 1
Case studies.

Case study	# of studies	Percentage (%)	Case study	# of studies	Percentage (%)
Numerical example	54	37.7%	Bangladesh	1	0.7%
Iran	18	13.0%	Ghana	1	0.7%
Turkey	13	9.4%	Nordic	1	0.7%
China	13	9.4%	Romania	1	0.7%
Lithuania	6	4.3%	Russia	1	0.7%
India	12	8.0%	Nigeria	1	0.7%
Spain	3	2.2%	Saudi Arabia	1	0.7%
EU	3	2.2%	Sub-saharan Africa	1	0.7%
Bosnia and Herzegovina	2	1.4%	UK	1	0.7%
Egypt	2	1.4%	US	1	0.7%
Afghanistan	2	1.4%	Uzbekistan	1	0.7%
Serbia	2	1.4%			

Table 2
Frequency of publications per first authors.

Authors	# of studies	Citations	Authors	# of studies	Citations
Keshavarz Ghorabaee et al.	12	1047	Madhu et al.	1	4
Stević et al.	5	169	Mathew and Sahu	1	44
Fan et al.	3	5	Mathew and Thomas	1	9
Li et al.	3	69	Matic et al.	1	0
Zhang et al.	4	97	Mi and Liao	1	25
Yazdani et al.	4	7	Mehdiabadi et al.	1	1
Stanujkic et al.	2	95	Mishra et al.	2	28
He et al.	2	15	Mitra et al.	1	0
Almutairi et al.	2	22	Mostafaeipour et al.	2	4
Ozcalici and Bumin	1	0	No et al.	2	2
Abdel-Basset et al.	2	16	Ouenniche et al.	1	5
Adali and Tus	1	4	Ozcelik and Nalkiran	1	3
Aggarwal et al.	1	10	Ozmen and Aydogan	1	8
Ali et al.	1	2	Palevicius et al.	1	15
Anilkumar et al.	1	3	Panchal et al.	1	1
Asante et al.	1	8	Pehlivan et al.	1	6
Ashraf et al.	1	0	Peng	1	3
Bączkiewicz et al.	1	4	Peng and Liu	1	139
Balali and Valipour	2	7	Peng et al.	1	36
Balezentis et al.	1	7	Polat and Bayhan	1	3
Batool et al.	1	3	Pramanik et al.	1	0
Behzad et al.	1	3	Qian et al.	1	7
Cereska et al.	1	17	Radwan et al.	1	0
Chairman et al.	1	1	Rakshit et al.	1	0
Chatterjee et al.	1	17	Rashid et al.	1	11
Chen et al.	1	13	Ren and Toniolo	1	42
Chinram et al.	1	9	Ren et al.	2	2
Dahooie et al.	1	3	Schitea et al.	1	27

(*continued on next page*)

Table 2 (*continued*).

Authors	# of studies	Citations	Authors	# of studies	Citations
Darko and Liang	1	13	Shinde et al.	1	0
Demirtas et al.	1	0	Shrivathsan et al.	1	0
Dhanalakshmi et al.	1	2	Skvarciany et al.	1	1
Ecer	1	63	Srivastava et al.	2	1
Feng et al.	1	15	Supciller and Toprak	1	1
Ghafari et al.	1	0	Tadic et al.	1	12
Han and Wei	1	1	Tan	1	0
Hasheminasab et al.	2	5	Tanwar et al.	1	0
Hashemkhani Zolfani et al.	1	1	Tolga and Basar	1	0
Hou et al.	1	6	Torkayesh et al.	1	0
Huang et al.	1	6	Turskis and Juodagalviene	1	42
Juodagalviene et al.	1	36	Turskis et al.	1	39
Kahraman et al.	1	124	U-Dominic et al.	1	0
Karasan and Kahraman	2	57	Valipour et al.	1	10
Karatop et al.	2	17	Vishnupriyan et al.	1	4
Kaviani et al.	1	6	Wang et al.	1	17
Kharazi et al.	1	3	Wei et al.	1	11
Kumar et al.	1	23	Xu et al.	1	1
Kundakci	1	10	Yahya et al.	1	0
Kutlu Gundogdu et al.	1	20	Yanmaz et al.	1	0
Krishankumar et al.	1	4	Ye et al..	1	2
Liang	1	2	Zavadskas et al.	3	59
Liang et al.	1	20	Zhan et al.	1	11

Table 3
Corresponding authors' location-based distribution of citations.

Country	Citations	Country	Citations
Iran	919	Pakistan	15
China	571	Thailand	15
Lithuania	364	Chile	7
Turkey	303	Spain	44
Bosnia and Herzegovina	169	Vietnam	6
India	143	Cyprus	6
Serbia	107	UK	5
Romania	27	Poland	4
Saudi Arabia	25	Nigeria	1
Egypt	2		

919, 571 and 364 respectively. On the other hand, Poland and Nigeria are the least cited countries as the number of citations is 4 and 1 respectively.

4.4. Journal distribution

The distribution of the journals regarding the number of publications is given in Table 4. "Journal of Intelligent & Fuzzy Systems", "Technological and Economic Development of Economy" and "Journal of Cleaner Production" are the most popular journals in the literature. Apart from these journals, there are 83 other journals in the literature preferred by the researchers. The distribution of the journals presents that the EDAS method is used by researchers from various disciplines for different purposes (e.g. Energy management, computer science, supply-chain management etc.). Furthermore, it can be observed from this distribution that the authors published their studies in both theoretical and industrial-based journals.

4.5. Combined methods

Fig. 4 discloses statistics of various MCDM methods in the literature combined with the EDAS approach. According to the table, most of the researchers preferred to combine EDAS with the AHP method. As AHP considers hierarchical structure in the decision-making process, is simple to apply real-world cases with a small or moderate number of criteria and is consistent in quality assurance, it is the most preferred technique by the researchers. After AHP, TOPSIS, SWARA and WASPAS are the most popular hybrid methods used with EDAS. As TOPSIS requires only a limited number of inputs and its outputs are simple to interpret, it is also one of the most preferred MCDM techniques in hybrid methods. As new MCDM utility determination techniques, SWARA and WASPAS are the most popular methods in the literature. As one of the SWARA method's main strengths is its ability to estimate the decision groups' opinions in the weight determination process, it is used by various researchers as a hybrid method with EDAS. The WASPAS method is also combined with the EDAS method regarding its accuracy in the evaluation of alternatives.

4.6. Uncertainty sets

Table 5 breaks down types of uncertainty sets that are used in the uncertain environment based EDAS publications in the literature. It exposes that most of the authors proposed an uncertainty-based EDAS approach that dealt with uncertainties via Type-1 Fuzzy Set. Intuitionistic Fuzzy Set and Grey Theory-based EDAS methods are also used as the second and third most popular uncertainty sets in EDAS applications. Apart from Type-1 Fuzzy Set, different variations of fuzzy sets e.g. Picture Fuzzy Set, Hesitant Fuzzy Set, Interval Type-2 Fuzzy Set, q-rung Orthopair Fuzzy Set, Four-Branch Fuzzy Set, Interval-Valued Fuzzy Sets based EDAS methods are also proposed in the literature. However, Type-1 Fuzzy Set is the most popular type preferred by the authors so far because of its simplicity and accuracy. Moreover, 56 of the publications reviewed in this study implemented the crisp EDAS method to the case studies.

4.7. Aggregation operators & information measures

Aggregation operators have become one of the significant concepts in decision-making problems under uncertainty. For example, in terms of fuzzy decision-making, t-norm and t-conorm are fundamental concepts applied to describe a generalized union and intersection of fuzzy sets. In this regard, the weighted arithmetic averaging operator, weighted geometric averaging operator, multiplicative exponential weighting, Hamacher aggregation operators, Frank aggregation operators, and Einstein aggregation operators are three well-known operators that are used to improve the traditional EDAS method under uncertainty sets such as various extensions of fuzzy sets, and rough set (Ashraf et al., 2021; Darko & Liang, 2020; Fan, Cheng, & Wu, 2019; Liu, Rani, & Pachori, 2021; Turskis & Juodagalvienė, 2016; Yahya et al., 2021).

Aggregation operators and information measures play important role in current real-life decision-making problems with high complexity and significance for the decision-makers. In this regard, behavioural

Table 4
Journals of published studies.

Journal	# of studies	Journal	# of studies
Journal of Intelligent & Fuzzy Systems	8	Grey Systems: Theory and Application	1
Technological and Economic Development of Economy	6	Groundwater for Sustainable Development	1
Journal of Cleaner Production	7	In Proceedings of the XLIII International Symposium on Operational Research	1
Sustainability	5	Informatica	1
IEEE Access	5	Information	1
Computers & Industrial Engineering	5	Information Sciences	1
International Journal of Hydrogen Energy	5	International Journal of Computational Intelligence Systems	1
Studies in Informatics and Control	3	International Journal of Construction Management	1
Mathematics	3	International Journal of Data and Network Science	1
Procedia Computer Science	2	International Journal of Computational Intelligence Systems	1
Kybernetes	2	International Journal of Fuzzy Systems	2
Management Decision	2	International Journal of Healthcare Management	1
Soft Computing	2	International Journal of Research Publication and Reviews	1
Symmetry	4	International Journal of Strategic Property Management	1
International journal of Computers Communications & Control	1	Journal of Air Transport Management	1
10th International Conference on Cloud Computing, Data Science & Engineering	1	Journal of Air Transport Management	1
Administrative Sciences	1	Journal of Ambient Intelligence and Humanized Computing	4
Advanced Engineering Informatics	1	Journal of Building Engineering	2
Advances in Fuzzy Logic and Technology	1	Journal of Business Economics and Management	1
Algorithms	1	Journal of Civil Engineering and Management	1
Applied Artificial Intelligence	1	Journal of Energy Storage	1
Applied Intelligence	1	Journal of Enterprise Information Management	1
Applied Sciences	1	Journal of Environmental Engineering and Landscape Management	1
Applied Soft Computing	2	Journal of Industrial Engineering and Decision Making	1
Arabian Journal for Science and Engineering	1	Journal of Multi-Criteria Decision Analysis	1
Archives of Civil and Mechanical Engineering	1	Journal of The Institution of Engineers (India)	1
Artificial Intelligence Review	1	Journal of Theoretical and Applied Electronic Commerce Research	1
Biomass Conversion and Biorefinery	1	Journal of Transport Geography	1
Complexity	2	Management Science Letters	1
Computational Intelligence and Neuroscience	1	Materials	2
Economic Computation & Economic Cybernetics Studies & Research	1	Mathematical Problems in Engineering	1
Ekonomika a Management	1	Oeconomia Copernicana	1
Energy	1	Plos One	1
Energy Policy	1	Processes	1
Energy Strategy Reviews	1	Science of the Total Environment	2
Engineering Applications of Artificial Intelligence	1	Soft Computing	2
Engineering Economics	1	Sustainable Development	1
Engineering Structures and Technologies	1	Sustainable Operations and Computers	1
Engineering Transactions	1	Technological and Economic Development of Economy	1
Environmental Science and Pollution Research	1	Transformations in Business & Economics	1
Fuel	1	Transport	1
Fundamenta Informaticae	1	Urban Forestry & Urban Greening	1
XLIII International Symposium on Operational Research	1	Case Studies in Thermal Engineering	1

Table 5
Uncertainty sets used for EDAS.

Uncertainty	# of studies	Uncertainty	# of studies
Crisp	56	2-tuple linguistic neutrosophic	1
Type-1 fuzzy set	27	Linguistic neutrosophic environment	1
Intuitionistic fuzzy set	6	Single-valued complex neutrosophic environment	1
Grey theory	4	Four-branch fuzzy set	2
Picture fuzzy set	3	Single-valued neutrosophic soft set	1
Probabilistic linguistic set	4	Interval numbers	2
Hesitant fuzzy set	3	Interval-valued complex fuzzy soft set	1
Interval type-2 fuzzy set	4	Interval-valued fuzzy set	1
Interval-valued neutrosophic set	2	Interval-valued Pythagorean fuzzy set	1
Single-valued neutrosophic set	2	Picture 2-tuple linguistic set	1
q-rung orthopair fuzzy set	3	Pythagorean 2-tuple linguistic set	1
Rough theory	2	Refined single-valued neutrosophic soft Set	1
2-dimension uncertain linguistic variables	1	Stochastic environment	1
Double hierarchy fuzzy set	1	Epistemic uncertainty	1
Fermatean fuzzy set	1	Interval rough	1
Intuitionistic fuzzy rough set	3	Pythagorean probabilistic hesitant fuzzy set	1
Trapezoidal bipolar fuzzy set	1	Trapezoidal neutrosophic set	1
Trapezoidal bipolar fuzzy set	1	Trapezoidal neutrosophic set	1

decision-making has become a significant concept in real-life problems with a high influence on decision-makers, experts, and stakeholders. Evidence theory and prospect theory are two well-known concepts that are frequently applied to improve MCDM methods such as EDAS to provide a flexible and reliable behavioural decision-making environment for decision-makers (Huang et al., 2021; Jiang, Wei, & Chen, 2022; Li, Liu, Wei, & Liu, 2021; Li & Wei, 2021).

4.8. Robustness of EDAS

The EDAS method is one of the very first methods which is based on an averaging normalization; however, most of the previous MCDM methods were based on the minimum and maximum normalization. This characteristic empowered the EDAS to address the MCDM problems with a generalized point of view. In this regard, Table 6 presents

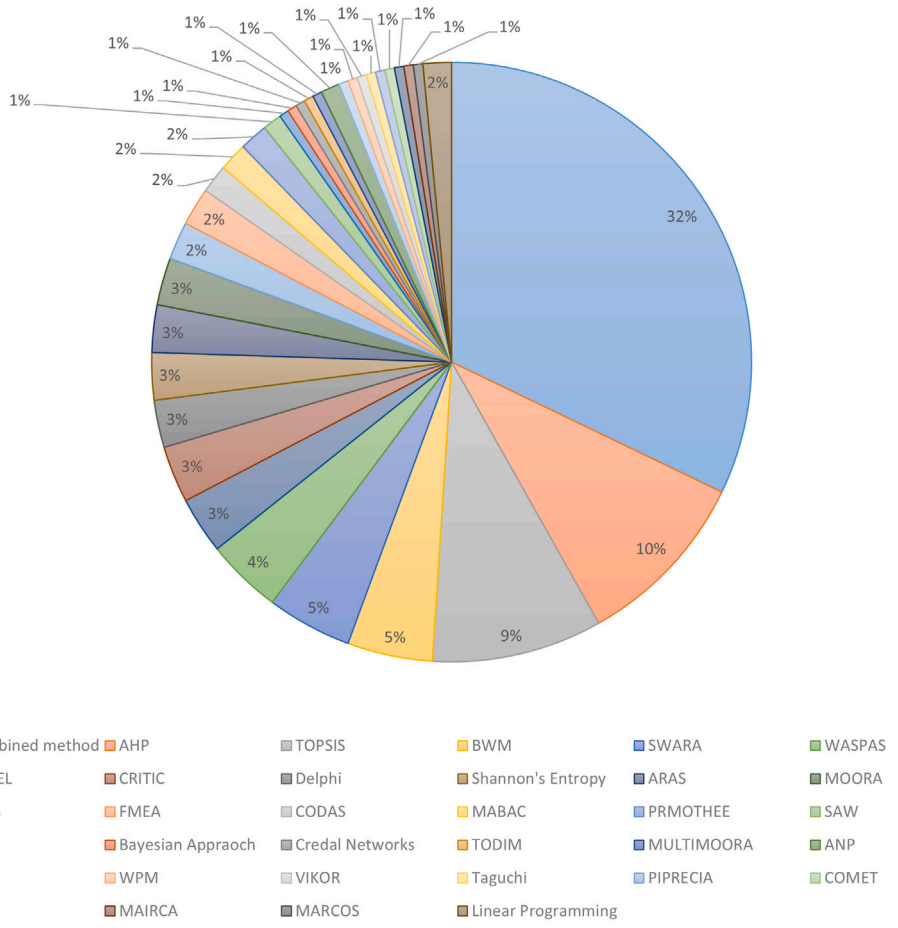

Fig. 4. Distribution of combined methods.

Table 6
Performance of EDAS compared to other MCDM methods.

Method	Computational time	Complexity
EDAS	Low	Moderate
CODAS	Moderate	High
TOPSIS	Moderate	Moderate
ELECTRE	High	High
PROMETHEE	High	Very high
VIKOR	Moderate	High
COPRAS	Moderate	Moderate
AHP	High	Moderate

a comparative performance analysis of several traditional MCDM methods and EDAS. EDAS method has a low computational time and moderate complexity.

Generally, the advantages of the EDAS are (i) low computational time, (ii) moderate mathematical and calculation complexity, (iii) flexible structure for decision-makers, (iv) using average solution-based normalization, (v) determining to rank based on two distance scores based on nature of criteria. As the EDAS determines a ranking score based on average solution-based distance measures rather than well-known measures such as Euclidean measure. Therefore, the EDAS can be empowered by integrating other methods such as CODAS. Integration of their outcomes would lead to more robust final results compared to the individual outcomes by addressing the existing issues. Moreover, the EDAS is not able to determine weight coefficients of criteria like ranking methods such as simultaneous evaluation of criteria and alternatives (SECA). Thus, EDAS has to be combined with weighting MCDM methods such as BWM to address an MCDM problem.

5. Applications

Based on the detailed review of published EDAS studies, nine applications groups are found out which cover all studies as (i) Agriculture; (ii) Business Management ; (iii) Construction Management; (iv) Energy and Natural Resources; (v) Healthcare Management; (vi) Technology; (vii) Manufacturing; (viii) Supply Chain Management; and (ix) Transportation Management. Fig. 5 presents the distribution of studies conducted in ten application areas. According to this figure, EDAS method is mostly applied in business management, construction management, supply chain management, and energy and natural resources.

In order to give more bibliometric information along with application category of each study, other information such as methodology, uncertainty type, objective, and case study location are given as well. Various MCDM problems in nine different application areas are handled with EDAS method under various uncertainty environment. Each fuzzy set which is used has its own advantages and disadvantages. The common purpose of these fuzzy sets is to better model uncertainty. Many parameters such as the number of criteria and alternatives, quantitative and qualitative criteria affect the choice of the method used.

Application based yearly distribution of studies is shown in Fig. 5 as well. It can be seen that the number of studies on EDAS method has increased from year to year. According to Fig. 5, EDAS studies were mostly carried out on construction management, business management, and energy and natural resources.

5.1. Agriculture

With the increase in the use of smart technologies and other machine tools in the field of agriculture, the quality and quantity of

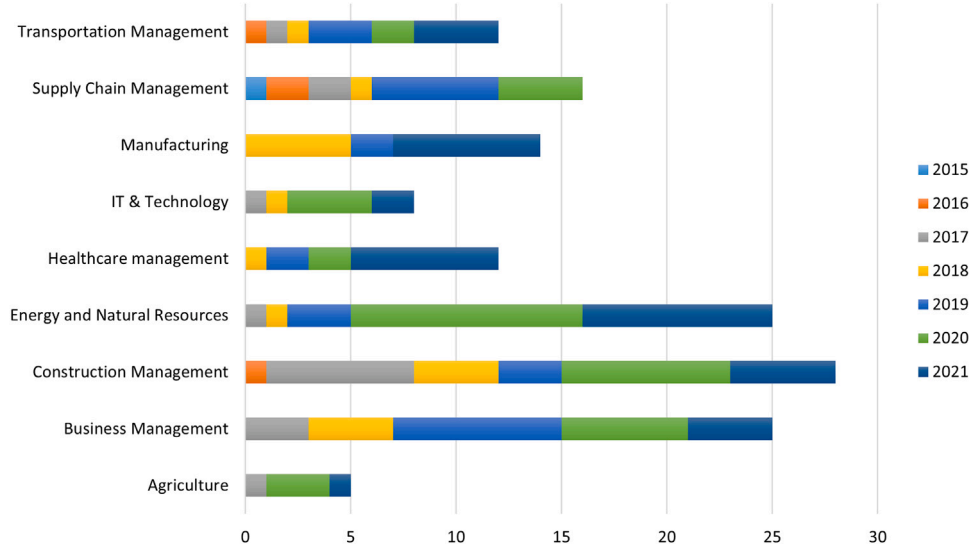

Fig. 5. Application based yearly distribution of studies.

Table 7
Applications of EDAS for agriculture.

Authors	Year	Methodology	Objective	Case study
Karaşan and Kahraman (2017)	2017	Interval-Valued Neutrosophic EDAS	Fertilizer supplier selection	–
Ghafari et al. (2020)	2020	Entropy, TOPSIS, ARAS, CODAS, EDAS	Prioritization of plant species	Iran
Balezentis et al. (2020)	2020	SAW, TOPSIS, Linear programming, EDAS	Optimizing crop mix	Europe
Tolga and Basar (2020)	2020	Type-1 TODIM, EDAS	Risk assessment	Turkey
Namiotko, Galnaityte, Krisciukaitiene, and Balezentis (2021)	2021	SAW, TOPSIS, EDAS	Evaluation of agricultural strategies	Europe

the products obtained have started to increase. Therefore, problems began to occur on the distribution and efficiency of the products. EDAS method is applied to the agriculture field, especially for supplier selection. Table 7 presents the applications of EDAS for agriculture. Karaşan and Kahraman (2017) studied with the supply chain managers of an agricultural company to choose the best fertilizer supplier. Five alternatives considering for four main and fifteen sub-criteria are ranked by interval-valued neutrosophic EDAS method. Balezentis et al. (2020) developed a framework for assessment of crop farming sustainability considering biodiversity, water footprint and economic indicators. They applied an integrated SAW, TOPSIS and EDAS methods to evaluate sustainability and used mathematical programming to describe scenarios. Ghafari et al. (2020) considered ecological potentials of trees, shrubs and hedge species for urban green spaces to assess the existing and recommended plant species by MCDM methods including EDAS, CODAS and ARAS.

The increasing population around the world is leading people to find a different type of feeding regime. Even with an enormous increase in crowd, brilliant innovators are looking for new ways to farm more efficiently. Hydroponics is one of the new ways to have a soilless cultivation system. The system reduces water usage by 95% and provides the same crop efficiency, and also ensures high sustainability. Tolga and Basar (2020) examined hydroponic system evaluation in urban farming via fuzzy EDAS and TODIM methods. In this study, the efficiency of this system presented investigated by minimizing the investment cost data.

5.2. Business management

MCDM methods are used as a solution method in many problems in the field of business management. These problems can be personnel selection, performance evaluation, investment option selection, economy policy selection, and credit evaluation for entrepreneurs. Businesses may encounter many situations that need to be decided by considering many criteria at the same time. Applications of EDAS for business management are presented in Table 8. Karabaševic et al. (2018) proposed an integrated EDAS and SWARA approach. While the SWARA method is used to determine the weights of the criteria, the newly proposed EDAS method is used to determine the ranking of alternatives. The usability and effectiveness of the proposed EDAS approach has been taken into account in the experimental implementation of the proposed model for the selection of IT Business Systems Support (BSS) Specialists. Peng and Liu (2017) evaluated four software projects including e-commerce development, game development, browser development, and web development project under three parameters using single-valued neutrosophic soft information. Qian et al. (2019) used the EDAS method to invest in the development of a new product for a company.

Table 8
Applications of EDAS for business management.

Authors	Year	Methodology	Objective	Case study
Keshavarz Ghorabaee et al. (2017b)	2017	Stochastic EDAS	Performance Evaluation of Bank Branches	USA
Peng et al. (2017)	2017	Interval-Valued fuzzy, Grey EDAS	Project Management	–
Karaşan and Kahraman (2017)	2017	Interval-valued Neutrosophic EDAS	United Nations Sustainable Development Goals Evaluation	Turkey
Stanujkic, Popovic, and Brzakovic (2018)	2018	SWARA, EDAS	Personnel selection	–
Feng et al. (2018)	2018	Hesitant fuzzy EDAS	Project Management	–
Chen et al. (2018)	2018	EDAS	Location Selection for a Teahouse	Lithuania
Mi and Liao (2019)	2019	Hesitant fuzzy BWM, EDAS	Evaluation of commercial endowment insurance products	China
He et al. (2019)	2019	Probabilistic Uncertain Linguistic based TOPSIS, EDAS	Green Supplier Selection	China
Mathew and Thomas (2019)	2019	EDAS	Flexible Manufacturing System Selection	India
Li, Wang, and Wang (2019)	2019	Linguistic Neutrosophic EDAS	Property Management Company Selection	China
Peng (2019)	2019	Intuitionistic fuzzy EDAS	Hotel Investment Selection	–
Fan, Cheng, and Wu (2019)	2019	Interval-valued complex fuzzy soft EDAS	Economic policy selection	–
Ouenniche et al. (2019)	2019	EDAS	Risk-class prediction	United Kingdom
Qian et al. (2019)	2019	EDAS	Investment selection	–
Ozcalici and Bumin (2020)	2020	MOORA, TOPSIS, EDAS	Assessment of the performance of publicly traded banks	Turkey
Mitra (2020)	2020	EDAS	Raw Jute Fibres Evaluation	India
No et al. (2020)	2020	Interval-number EDAS	Performance Evaluation of Bank Branches	Iran
Ren et al. (2020)	2020	Four-Branch Fuzzy EDAS	Credit Evaluation for Micro and Small Entrepreneurs	China
Skvarciany et al. (2020)	2020	EDAS	Socioeconomic Development Evaluation	EU
Han and Wei (2020)	2020	Neutrosophic EDAS	Investment option selection	–
Demircan and Acarbay (2022)	2021	Neutrosophic EDAS	Vendor selection	–
Huang et al. (2021)	2021	EDAS under prospect theory	Enterprise selection	–
Wang, Xu, and Gou (2021)	2021	Interval probabilistic double hierarchy linguistic EDAS, Natural language processing	Hotel online reviewing	China

Three types of development plans was examined under three different criteria.

5.3. Construction management

Construction management problems also involve many MCDM problems such as project management (Liang, 2020), subcontractor evaluation (Keshavarz Ghorabaee, Amiri, Zavadskas, & Turskis, 2017; Keshavarz Ghorabaee et al., 2018b; Stanujkic et al., 2017), construction equipment evaluation (Keshavarz Ghorabaee et al., 2018), risk and safety assessment (Valipour et al., 2018; Wang et al., 2019), material assessment (Hasheminasab et al., 2019), investment project selection (Fan et al., 2020), cultural heritage site evaluation (Abdel-Basset et al., 2020), loaders selection (Zhang et al., 2020) and so on. Although intensive research on MCDM approaches has been carried out on subcontractor selection and risk assessment, it can be still adapted to various construction management problems. The applications of EDAS for construction management are given in Table 9.

5.4. Energy & natural resources management

There are many studies in the literature on renewable energy, energy planning, energy investment, waste management, and energy supply/demand. In recent years, MCDM techniques have been widely used to solve energy & natural resources management problems as given in Table 10. Many studies have been conducted especially in the selection of renewable energy resources which consist of solar energy, wind energy, tidal energy, hydro energy, biomass energy, geothermal energy and other mixed energy systems. Today, site selection and ranking of alternatives are an important decision problem in the installation of renewable energy systems. Some of the studies are as follows: the evaluation of renewable energy resources (Karatop et al., 2020; Yazdani, Torkayesh, et al., 2020), wind turbine selection (Supciller & Toprak, 2020), waste disposal site selection (Kahraman et al., 2017), and the selection of waste management performances (Behzad et al., 2020).

5.5. Healthcare management

There is an increasing need to solve MCDM problems in the healthcare sector. Nowadays, various existing studies have focused on the application of MCDMs and various uncertain environments to solve health management problems. Some applications of EDAS for healthcare management are given in Table 11. These applications are as follows: hospital selection for organ transplantation (Kutlu Gündoğdu et al., 2018), emergency management center selection (Li, Ju, et al., 2019), hospital location selection (Adalı & Tuş, 2019), evaluation of the hospital healthcare in terms of waste disposal technology (Mishra, Mardani, et al., 2020), and supplier evaluation in public healthcare (Yazdani, Chatterjee, & Torkayesh, 2020).

5.6. Information technology (IT)

Information technology (IT) which includes design, development, implementation, support or management of computer-based information systems is an important management tool and applicable not only to large businesses but also to small businesses despite their limited resources. Recent years have seen IT problems based MCDM which includes EDAS in the literature such as the project selection software development (Peng & Liu, 2017), evaluation of mobile payment systems (Darko & Liang, 2020), and network security assessment (Tanwar et al., 2020). Applications of EDAS for information technology are presented in Table 12.

5.7. Manufacturing

Manufacturing industries face many challenges due to globalization and rapidly changing market demand, resulting in higher production requirements and more complex parts (Sahal, Breslin, & Ali, 2020). It includes many important issues in terms of MCDM problems such as facility location selection, equipment selection (Mathew & Sahu, 2018), industrial robot selection for smart factories (Fan, Li, & Wu, 2019), cleaner production method selection (Liang et al., 2018), critical material selection (Chatterjee et al., 2018) and so on. Studies use of EDAS to solve this problem are given in Table 13.

5.8. Supply chain management

Until recently, the intense competition between companies has started to occur on the basis of supply chains today. The success and performance of the supply chain as a whole requires coordination and harmony at every stage of the chain. The change in customer expectation has been eliminated after the recognition of the price factor as the only and sufficient determinant in the purchasing decision, and the need for supply chains that will create products that will provide price quality, speed in delivery, reliability and high quality (Uludag & Deveci, 2013). The studies on supply chain management using EDAS method are presented in Table 14. It can be seen that many different

Table 9
Applications of EDAS for construction management.

Authors	Year	Methodology	Objective	Case study
Turskis and Juodagalvienė (2016)	2016	AHP, SAW, TOPSIS, EDAS	Stair shape assessment	–
Turskis, Morkunaite, and Kutut (2017)	2017	AHP, EDAS	Cultural heritage site evaluation	Lithuania
Keshavarz Ghorabaee, Amiri, Zavadskas, and Turskis (2017)	2017	Interval Type-2 Fuzzy EDAS	Subcontractor evaluation	–
Stanujkic et al. (2017)	2017	Grey EDAS	Subcontractor evaluation	Iran
Zavadskas et al. (2017)	2017	EDAS	Sustainable development evaluation	Lithuania
Stević et al. (2017)	2017	Rough DEMATEL, EDAS	Supplier selection	–
Juodagalvienė et al. (2017)	2017	SWARA, EDAS	Evaluation of house's plan shape	Lithuania
Valipour et al. (2018)	2018	Type-1 Fuzzy AHP, ANP, Delphi, EDAS	Risk assessment	Iran
Čereška et al. (2018)	2018	EDAS	Diagnostics of wire rope	–
Keshavarz Ghorabaee et al. (2018)	2018	Type-1 Fuzzy SWARA, CRITIC, EDAS	Construction equipment evaluation	Iran
Wang et al. (2019)	2019	2-tuple linguistic neutrosophic EDAS	Risk and safety assessment	–
Hasheminasab et al. (2019)	2019	Type-1 Fuzzy Delphi, EDAS	Material assessment	Iran
Yazdani, Abdi, Kumar, Keshavarz-Ghorabaee, and Chan (2019)	2019	Type-1 Fuzzy ANP, FMEA, EDAS	Evaluation of water reservoirs and dams projects	Europe
Zhang et al. (2020)	2020	2-dimension uncertain linguistic AHP, EDAS	Loaders selection	–
Balali and Valipour (2020)	2020	BWM, EDAS	Prioritization of passive measures for energy optimization	Iran
Torkayesh, Amiri, Iranizad, and Torkayesh (2020)	2020	Entropy, EDAS	NEIGHBORHOOD selection	Turkey
Polat and Bayhan (2020)	2020	Type-1 Fuzzy EDAS	Supplier selection	Russia
Liang (2020)	2020	Intuitionistic fuzzy EDAS	Project management	China
Tan et al. (2020)	2020	Refined Single-Valued Neutrosophic Soft EDAS	Disaster assessment	China
He et al. (2020)	2020	Pythagorean 2-tuple linguistic EDAS	Construction safety assessment	–
Fan et al. (2020)	2020	Neutrosophic EDAS	Investment project selection	–
Hou et al. (2021)	2021	Type-1 fuzzy EDAS, Bayesian networks, Credal networks	Safety risk assessment	China
Jana and Pal (2021)	2021	Bipolar fuzzy EDAS	Road construction project selection	–
Li et al. (2021)	2021	Pythagorean fuzzy EDAS under prospect theory	Investment project selection for highways	China

(*continued on next page*)

Table 9 (*continued*).

Authors	Year	Methodology	Objective	Case study
Kharazi, Heshmatpour, et al. (2021)	2021	GIS, AHP, TOPSIS, EDAS	Dam construction site selection	Iran
Ye et al. (2021)	2021	Fuzzy rough PROMETHEE II, EDAS	Building shape selections	–

Table 10
Applications of EDAS for energy and natural resources management.

Authors	Year	Methodology	Objective	Case study
Kahraman et al. (2017)	2017	Intuitionistic fuzzy EDAS	Solid waste disposal site selection	–
Ren and Toniolo (2018)	2018	Type-1 fuzzy LCA, AHP, DEMATEL	Evaluation of hydrogen production pathways	–
Zhang, Wei, et al. (2019)	2019	TOPSIS, WASPAS, Monte Carlo Simulation, EDAS	Assessment of renewable micro-generation technologies in households	Lithuania
Schitea et al. (2019)	2019	Intuitionistic fuzzy sets WASPAS, COPRAS, EDAS	Hydrogen mobility roll-up site selection	Romania
Kharazi et al. (2019)	2019	GIS, AHP, TOPSIS, EDAS	Location selection of underground dam	Iran
Hasheminasab et al. (2020)	2020	Grey WASPAS, CODAS, EDAS	Evaluation of petroleum refinery projects	Iran
Behzad et al. (2020)	2020	BWM, EDAS	Evaluation of waste management performances	Nordic countries
Karatop et al. (2020)	2020	Type-1 Fuzzy AHP, FMEA, EDAS	Selection renewable energy investments	Turkey
Abdel-Basset et al. (2020)	2020	Single-valued neutrosophic AHP, COPRAS, EDAS	Evaluation of sustainable hydrogen production options	–
Mostafaeipour et al. (2020)	2020	SWARA, EDAS	location selection for harnessing wind energy to produce hydrogen	Afghanistan
Asante et al. (2020)	2020	MULTIMOORA, EDAS	Evaluation of barriers to renewable energy adoption	Ghana
Ali et al. (2020)	2020	BWM, EDAS	Prioritizing power generation technologies	Bangladesh
Supciller and Toprak (2020)	2020	Single valued neutrosophic SWAR, TOPSIS, EDAS	Selection of wind turbines	Turkey
Madhu et al. (2020)	2020	Type-1 Fuzzy AHP, VIKOR, TOPSIS, PROMOTHEE, EDAS	selection of a suitable biomass material for maximum bio-oil yield during pyrolysis	–
Dhanalakshmi et al. (2020)	2020	Type-1 Fuzzy AHP, TOPSIS, EDAS	Biomass material evaluation	–
Yazdani, Torkayesh, et al. (2020)	2020	Entropy, EDAS	Evaluation of renewable energy resources	Saudi Arabia
Chinram et al. (2021)	2021	Intuitionistic fuzzy rough EDAS	Small hydro-power plant selection	–
Demirtas et al. (2021)	2021	Trapezoidal fuzzy EDAS, AHP	Renewable resource selection	Turkey
Yahya et al. (2021)	2021	Intuitionistic fuzzy EDAS under Rough Frank Aggregation Operators	Hydro-power plant selection	–
Anilkumar, Maniyeri, and Anish (2021)	2021	TOPSIS, MOORA, AHP, CRITIC, Shannon's Entropy, EDAS	Phase change material selection	–
Babatunde et al. (2021)	2021	EDAS	Energy system selection	Nigeria
Almutairi, Dehshiri, Dehshiri, Mostafaeipour, Issakhov, and Techato (2021)	2021	SWARA, EDAS	Hydrogen production for wind energy	Iran
Almutairi, Dehshiri, Dehshiri, Mostafaeipour, Jahangiri, and Techato (2021)	2021	GIS, SWARA, EDAS	Hydrogen production for wind energy	Afghanistan
Ullah, Elkadeem, Kotb, Taha, and Wang (2021)	2021	GIS, Type-1 fuzzy AHP, TOPSIS, EDAS, MOORA	Optimal planning of on/off grid hybrid clean electricity supply	Pakistan
Mostafaeipour et al. (2021)	2021	BWM, EDAS	optimal planning of on/off grid hybrid clean electricity supply	Uzbekistan

Table 11
Applications of EDAS for healthcare management.

Authors	Year	Methodology	Objective	Case study
Kutlu Gündoğdu et al. (2018)	2018	Hesitant fuzzy set EDAS	Hospital selection for organ transplantation	Turkey
Li, Ju, et al. (2019)	2019	Picture fuzzy EDAS	Emergency management center selection	China
Adalı and Tuş (2019)	2019	CRITIC, EDAS	Location selection for a Hospital	Turkey
Mishra, Mardani, et al. (2020)	2020	Intuitionistic fuzzy sets EDAS with divergence measure	Healthcare waste disposal technology evaluation	–
Yazdani, Chatterjee, and Torkayesh (2020)	2020	DEMATEL, BWM, EDAS	Supplier evaluation in public healthcare	Spain
Batool et al. (2021)	2021	Pythagorean probabilistic hesitant fuzzy EDAS	COVID-19	–
Özçelik and Nalkıran (2021)	2021	Trapezoidal bipolar fuzzy EDAS	Medical device selection	Turkey
Yılmaz and Atan (2021)	2021	Type-1 fuzzy EDAS	Hospital site selection	Turkey
Bashiri, Alizamini, and Nasrabadi (2021)	2021	Type-1 fuzzy BWM, EDAS	Health tourism management	Iran
Kumar et al. (2021)	2021	WSM, WPM, WASPAS, EDAS, TOPSIS	Material selection for knee Implant Femoral Component	–
Sahoo and Choudhury (2022)	2021	Shannon's entropy, COPRAS, EDAS	Electric power wheelchair selection	–

studies have been published as follows: supplier selection (Kaviani et al., 2019; Keshavarz Ghorabaee, Amiri, Zavadskas, & Turskis, 2017; Xu et al., 2020), green supplier selection (Zhang, Gao, et al., 2019), logistics center location selection (Özmen & Aydoğan, 2020), inventory classification (Keshavarz Ghorabaee et al., 2015), supply chain risk management (Yazdani, Gonzalez, & Chatterjee, 2019) and so on. There

Table 12
Applications of EDAS for information technology.

Authors	Year	Methodology	Objective	Case study
Peng and Liu (2017)	2017	Grey system, single-valued neutrosophic EDAS	Software development project selection	China
Aggarwal et al. (2018)	2018	EDAS	Evaluation of smart phones	–
Srivastava et al. (2020)	2020	EDAS	Evaluation of autonomous maintenance systems	India
Darko and Liang (2020)	2020	Hamacher aggregation operators based EDAS	Evaluation of mobile payment systems	Sub-saharan Africa
Shrivathsan et al. (2020)	2020	Probabilistic linguistic information based EDAS	Test case prioritization	India
Tanwar et al. (2020)	2020	EDAS	Network security assessment	India
Ashraf et al. (2021)	2021	q-Rung Orthopair Fuzzy Rough EDAS with Einstein aggregation	Robotic agriculture farming	Pakistan
Stanujkić et al. (2021)	2021	Single-Valued Neutrosophic EDAS	University tablet selection	–

Table 13
Applications of EDAS for manufacturing.

Authors	Year	Methodology	Objective	Case study
Ghorabaee, Amiri, Zavadskas, Turskis, and Antucheviciene (2017)	2017	Multi-objective linear programming, Interval type-2 fuzzy sets EDAS	Supplier evaluation and order allocation	–
Mathew and Sahu (2018)	2018	EDAS	Material handling equipment selection	–
Liang et al. (2018)	2018	Picture fuzzy ELECTRE, EDAS	Selection of cleaner production for gold mines	–
Stević et al. (2018)	2018	Type-1 EDAS	Selection of manufacturer of PVC carpentry	–
Pehlivan et al. (2018)	2018	Type-1 AHP, WASPAS, ARAS, EDAS	Selection of organizational strategy	–
Chatterjee et al. (2018)	2018	Type-1 DoE, EDAS	Critical material selection	–
Kundakcı (2019)	2019	Type-1 MACBETH, EDAS	Evaluation of steam boiler alternatives	Turkey
Fan, Li, and Wu (2019)	2019	EDAS	Robot selection	–
Chairman et al. (2021)	2021	Taguchi, EDAS	Mechanical performance of TiO_2 filled woven glass fibre reinforced polymer composites	–
Chairman et al. (2021)	2021	Pythagorean fuzzy EDAS, weighted sum measure	Sustainable circular supplier selection	China
Mao, Liu, Mou, and Liu (2021)	2021	Linguistic Z-Number based EDAS, Quality function deployment, SWARA	Car design	China
Mishra et al. (2021)	2021	Fermatean fuzzy EDAS, CRITIC	sustainable third-party reverse logistics provider selection	India
Rashid et al. (2021)	2021	BWM, EDAS	Robot selection	–
U-Dominic et al. (2021)	2021	DEMATEL, Intuitionistic fuzzy EDAS	Reverse logistics evaluation	Nigeria
U-Dominic et al. (2021)	2021	Probabilistic linguistic EDAS	Green supplier selection	–

are some MCDM methods have been developed to address supply chain management problems,

5.9. Transportation

In recent years, the issue of sustainability in terms of competition has been the focus of the transportation industry (Shi, Arthanari, Liu, & Yang, 2019). The field of transportation contains many decision problems. Applications of EDAS for transportation management in different fields are presented in Table 15. There are some combinations of other MCDM methods for different transportation problems such as evaluation of city Logistics using AHP and EDAS (Stević et al., 2016), selection of inland intermodal terminals using DEA and EDAS (Tadić et al., 2019), car selection using PROMOTHEE and EDAS (Zhan et al., 2020), the evaluation of the proper metro and tram vehicle for urban transportation using CRITIC and EDAS method (Görçün, 2021), and the evaluation of zero-carbon measures for sustainable urban mobility with the help of integrated double hierarchy decision framework and EDAS approach (Krishankumar et al., 2021).

6. Discussions & conclusion

In this review, a comprehensive literature review of MCDM publications which use EDAS method is performed to guide and encourage the researchers for future contributions. Within this scope, 146 publications are reviewed as full text and scrutinized. As an output of this comprehensive review, it is highlighted that there is a significant increase in the number of case studies in the literature which deal with MCDM problems using the EDAS method. Furthermore, the variety in the scope of the case studies is being sufficiently progressed within the years. Majority of the publications dealing with MCDM problems with EDAS method are related to construction management, business, and energy-related topics. On the other hand, the number of cases which deal with problems in the scope of social sciences e.g. evaluation of the goals

Table 14
Applications of EDAS for supply chain management.

Authors	Year	Methodology	Objective	Case study
Keshavarz Ghorabaee et al. (2015)	2015	EDAS	Inventory classification	–
Stević et al. (2016)	2016	AHP, EDAS	Ranking of city logistics scenarios	Serbia
Keshavarz Ghorabaee, Zavadskas, Amiri, and Turskis (2016)	2016	Type-1 EDAS	Supplier selection	–
Keshavarz Ghorabaee et al. (2017a)	2017	Interval type-2 fuzzy sets LP, EDAS	Supplier selection	–
Keshavarz Ghorabaee, Amiri, Zavadskas, and Turskis (2017)	2017	Type-1 Fuzzy EDAS	Supplier selection	Iran
Ecer (2018)	2018	Type-1 Fuzzy AHP, EDAS	Third-party logistics provider selection	Turkey
Zhang, Gao, et al. (2019)	2019	Picture 2-Tuple Linguistic EDAS	Supplier Selection	–
Zhang, Wei, et al. (2019)	2019	Picture fuzzy EDAS	Green supplier selection	–
Stević et al. (2019)	2019	Type-1 fuzzy AHP, EDAS	Evaluation of suppliers	Bosnia and Herzegovina
Yazdani, Gonzalez, and Chatterjee (2019)	2019	SWARA	Supply chain risk management	Spain
Yazdani, Chatterjee, et al. (2019)	2019	Type-1 fuzzy DEMATEL, EDAS	Green supplier selection	Spain
Kaviani et al. (2019)	2019	Delphi based EDAS	Supplier selection for oil and gas industry	Iran
Xu et al. (2020)	2020	A Single-valued complex neutrosophic EDAS	Supplier selection	–
Özmen and Aydoğan (2020)	2020	–	Logistics center location selection	Turkey
Dahooie et al. (2020)	2020	Delphi based EDAS	Prioritizing cost reduction solutions	Iran
Li et al. (2020)	2020	Q-rung orthopair fuzzy EDAS	Evaluation of refrigerator	–

Table 15
Applications of EDAS for transportation management.

Authors	Year	Methodology	Objective	Case study
Stević et al. (2016)	2016	AHP, EDAS	Scenario evaluation of city logistics	Bosnia and Herzegovina
Keshavarz Ghorabaee et al. (2017a)	2017	Probability distribution based EDAS	Evaluation of airlines	–
Palevičius et al. (2018)	2018	EDAS	Public infrastructure evaluation	Lithuania
Tadić et al. (2019)	2019	Type-1 Fuzzy DEA, EDAS	Selection of inland intermodal terminals	Europe
Zavadskas et al. (2019)	2019	CRITIC, TOPSIS, WASPAS, EDAS	Evaluation of autonomous vehicles	–
Zhan et al. (2020)	2020	Rough PROMOTHEE, EDAS	Car selection	China
Yanmaz, Turgut, Can, and Kahraman (2020)	2020	Interval-valued Pythagorean Fuzzy EDAS	Car selection	–
Görçün (2021)	2021	CRITIC and EDAS	Selection of the urban rail vehicle	–
Krishankumar et al. (2021)	2021	Hesitant fuzzy EDAS	Prioritizing zero-carbon measurements	India
Wu, Li, and Fan (2021)	2021	BWM, MULTIMOORA, EDAS	Evaluation of new energy vehicle	China
Görçün (2021)	2021	CRITIC, EDAS	Urban rail vehicle selection	Turkey

of UN, agricultural policy determination, economical analyses have significantly increased recently. These findings state that EDAS has the significant potential not only in engineering applications but also in social science-related, environmental, and economic problems. The fact remains that the results of this review depict that EDAS has been combined with various MCDM techniques e.g. AHP, TOPSIS, SWARA. Furthermore, there are a reasonable number of EDAS publications in the literature which deal with uncertainty with various types of uncertainty based extension of EDAS e.g. Type 1 fuzzy set, intuitionistic fuzzy set, grey theory, interval-valued neutrosophic set et al. This output underlines that EDAS has potential for the future studies which deal with cases in uncertain environments via hybrid EDAS methods.

Although the review provided significant implications, several challenges were identified which can be addressed as future directions. For the future directions, EDAS method can be utilized and extended in different ways. One of the ways to enhance the capability of decision making environment and decrease any information-related issues, different operators such as dombi norms, weighted power heronian, weight geometric power heronian. Integration of such operators can strongly decrease effect of extreme and unreasonable arguments in initial decision-making matrix. Another important direction is to extend EDAS method under novel fuzzy environments in order to involve more precise form of uncertain judgments of real-life decision makers. On other hands, preference of decision makers can also increase the reliability of future EDAS extensions under preference-based approaches (Guo, Zhang, Gong, Zhang, & Yang, 2019). Due to complexity of the decision making problems, consolidating decision maker's opinions and experts can be very useful for enhancing the reliability of the EDAS's solution by using extended Z-numbers (Tian, Mi, Ji, & Kang, 2021). By the rise of concepts like big data, decision making has entered to a new era. One of the potential future directions is to integrate EDAS

with data mining and machine learning algorithms such as clustering and classification algorithms in order to construct reliable decision support systems (Simic, Ebadi Torkayesh, & Ijadi Maghsoodi, 2022). Most of the decision making studies focus on uncertainty in information regarding opinions of decision makers; however, there exist a great research gap in considering uncertainty in decision making environment. In other words, most of decision making problems solved with MCDM methods consider a deterministic environment while making a decision; however, current situations can go through different conditions in future and uncertain events in future can obsolete the findings of decision making process over years. Therefore, there exist a great need to consider doubts of decision makers regarding future uncertain events. Concept of stratification (Asadabadi, 2018; Torkayesh, Malmir, & Asadabadi, 2021) can be integrated with EDAS method in order to incorporate future uncertain events and decision makers' doubts into decision making process. Moreover, for real-life decision makings under high complicated structures, EDAS can be combined with system dynamic and simulation modelling for generating reliable solutions.

In addition, a wide range of data normalization techniques is available in the literature, and the most commonly used are the following: Vector normalization, linear normalization, min–max normalization, non-monotone normalization, Weitendorf linear normalization method, Juttler–Korth normalization method and Peldschus nonlinear normalization (Mukhametzyanov, 2021; Pamucar & Ecer, 2020; Peldschus, Vaigauskas, & Zavadskas, 1983; Prasenjit et al., 2021; Zolfani, Yazdani, Pamucar, & Zarate, 2020). These normalization techniques can be used in the EDAS method in the future. Distance measures are also an important mathematical tool to calculate the difference degree between fuzzy sets. Its functions can be used in many fields of science for quantitative evaluations of similarities as well as comparisons of items (Ilieva, Yankova, & Klisarova-Belcheva, 2018). Various distance measures have been proposed in the literature such as Taxicab distance, Euclidean distance, Gower distance, Soergel distance, Kulczynski distance, Canberra distance, Lorentzian distance and so on (Cha, 2007; Choi, Cha, & Tappert, 2010; Choi et al., 2010; Ilieva et al., 2018).

CRediT authorship contribution statement

Ali Ebadi Torkayesh: Conceptualization, Methodology, Validation, Investigation, Writing—original draft, Writing – review & editing, Visualization. **Muhammet Deveci:** Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Selman Karagoz:** Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Jurgita Antucheviciene:** Writing – original draft, Writing – review & editing, Supervision.

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

No data was used for the research described in the article.

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