Journal of Open Innovation: Technology, Market,and Complexity 9 (2023) 100096

Contents lists available at ScienceDirect

Journal of Open Innovation: Technology, Market, and Complexity

journal homepage: www.sciencedirect.com/journal/joitmc

Prioritization of technology commercialization success factors using fuzzy best worst method

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ARTICLE INFO

Keywords:
Technology Commercialization
Best Worst Method
Prioritization
University
Innovation
Entrepreneurship

ABSTRACT

The existence of intense competition in the global market has pressurized organizations to increasingly survive. Many universities strive to create technologies because of their enormous influence on the universities' development and values. However, the success of achieving this task is arduous due to several commercialization-related difficulties assessing the potential of technology commercialization (TC) in universities. The purpose of this study is to identify and prioritize the factors that influence the development and commercialization of software products in universities. The criteria were identified via a literature review and Delphi study. Fuzzy best worst method (BWM) was applied to prioritize the criteria. The outcomes of fuzzy BWM were validated with fuzzy analytic hierarchy process via comparative analysis. The results of the fuzzy BWM revealed the orders of priority of the criteria from the most important to the least important as entrepreneurial capability, funding, R&D capability, networking, marketing, distinctive features, intellectual property protection, motivational aids, and knowledge-sharing culture. However, the comparative analysis of the outcomes for the 2 multi-criteria decision-making methods indicated that the rankings of the criteria are the same except for the changes between the sixth and seventh criteria. The difference in subjectivities among the experts based on their diverse backgrounds could be a factor contributing to this disparity. This research contributes to existing research by identifying and prioritizing the criteria that influence the performance of TC which have not been previously addressed by using fuzzy BWM. Fuzzy BWM was established to be more consistent and efficient in the decision-making process.

1. Introduction

It is well recognized that technological development is the impetus behind the creation of goods and services, competitiveness in the market, and opportunities for boosted trade (Isioto et al., 2017). Technology development can foster economic growth if innovative products are commercialized by introducing the products into the market to generate income for organizations and other key players such as researchers, policymakers, and entrepreneurs (Zemlickienė and Turskis, 2020).

The commercialization of technologies developed by universities, government-funded laboratories, or research institutes can be achieved through diverse methods such as selling, exchanging, and licensing (Nugent and Chan, 2023). The process of TC is considered a crucial component of technology management (Kim and Cho, 2022).

There are numerous advantages to successfully commercialize a new product namely; the creation of jobs, licensing, monetary rewards, and income generation, among others (Dhewanto and Sohal, 2015; Tawate et al., 2022). Successful TC aids an organization to fulfil its customers' demands through the cost, quality, technological diffusion, and innovative features of the technologies (Park and Rhee, 2013).

TC appears to be a herculean task in any firm with longer timespans for technology innovation. Development of new products in a firm required an enormous task because the market could alter as the technology is being created. This consequentially requires changes to the technology throughout its development processes (van Rooyen et al., 2020). Huge resources have been expended on research and development (R&D) but the rate of successful commercialization is found to be lesser than anticipated. This implies the wastage of a huge amount of money and time (Zemlickienė, 2018; Zemlickienė et al., 2017).

Assessing the potential for TC of any products by decision-makers is challenging. However, measuring TC is crucial in decision-making

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https://doi.org/10.1016/j.joitmc.2023.100096
Received 22 May 2023; Received in revised form 2 July 2023; Accepted 11 July 2023
Available online 13 July 2023

because it uncovers the economic potential of the technologies or products (Zemlickienė, 2019). TC can be used to determine future competitive power as well as commercialization potential of organizations in a competitive setting. It enables organizations to minimize errors, shorten the time required to bring products to market, and ensure prompt decision-making in time-sensitive situations (Kim et al., 2021). It also helps decision-makers such as policymakers and governments to determine which businesses to support and the degree of supportiveness to the firms (Altuntas and Dereli, 2012).

The factors/criteria affecting the commercialization of technology are numerous and linked with the technical, financial, market, as well as other relevant aspects; hence the relationship between these components and their impact on the commercialization process is crucial (Zemlickienė and Turskis, 2022a). The relative significance of these factors needs to be evaluated to identify the impact of each criterion on the success of TC and the enhancement of evaluation models (Yazdimoghaddam et al., 2019). Thus, applying a suitable technique for assessing the relative significance of the factors influencing the performance of TC is of high importance.

Several studies have been conducted on ranking the relative importance of factors that affect TC using different multi-criteria decision making (MCDM) techniques. The relative significance of the factors that influence the performance of TC has been investigated using the analytic hierarchy process (AHP) (Cho and Lee, 2013; Lee et al., 2016; Park et al., 2017). The main feature of the AHP technique is the application of pairwise comparisons at each hierarchy level to evaluate alternatives with regard to the different criteria as well as to estimate weights of criteria. The method has underlying shortcomings of the inability to handle problems with nonlinear structure and the pairwise comparisons of criteria by decision makers are time-consuming (Thakkar, 2021).

Consistency is one of the major challenges for decision-makers when applying MCDM methods. Thus, the best-worst method (BWM) was introduced by Rezaei (2015) to address this inconsistency. BWM applies preference comparisons to the criteria, in which the most important criterion is compared with the other criteria, and the other criteria are compared with the least important criterion (Dong et al., 2021). This process makes the pairwise comparison of this technique less computational when compared to other MCDM approaches. BWM is also simpler and more consistent than AHP (Guo and Zhao, 2017). However, its problem of inability to handle inaccurate and vague data in a fuzzy environment can be addressed by adopting fuzzy BWM (Soner et al., 2022). Fuzzy BWM was used in this research for prioritization of the factors that influence the TC performance due to its strengths, especially its high consistency, and simplicity in application.

Moreover, to the best knowledge of the authors, there is a lack of studies that adopted fuzzy BWM for determining the ranking and relative importance of each factor that affects TC performance. The objectives of this research are to evaluate the weights of the criteria that influence the success of TC and to validate the outcome via comparative analysis with the fuzzy AHP method.

This study applies fuzzy BWM to experts' judgements (after the Delphi study) on preference comparisons of the factors that affect TC of software-based products in the fuzzy environment. This research contributes to the existing understanding that the TC process of software products in an organization can be efficiently managed by decision-makers. The comprehensive analysis of this study contributes to existing research by identifying the criteria that should be considered in the performance of TC and holistically examining the priorities of these criteria that have not been previously addressed using fuzzy BWM.

The remaining part of this paper is structured as follows: the literature review of TC and its factors is provided in Section 2; the methodology and data collection are presented in Section 3 and Section 4 correspondingly. The results and discussion are presented in Section 5. In Section 6, the implications of the research are described. Finally, Section 7 covers the conclusions.

2. Literature Review

2.1. Technology Commercialization

Commercialization is the process of introducing a product to the marketplace as well as the dissemination of innovation (Kenzhaliyev et al., 2021; Khalil Zadeh et al., 2017). Tawate et al. (2022) described TC as the means of transforming technological ideas into marketable new products that benefit society. The concept of TC encapsulates the creation of ideas with complementary knowledge, design, prototyping, testing stages, and efficient commercialization of manufactured products (Baron, 2021). The commercialization of a product is a crucial step in the innovation process, and without it, no product or technology can be successfully introduced into the market (Bakhtiar et al., 2020; Datta et al., 2015). The products that are introduced into the market originate from organizations such as universities and other research institutes, technology startups, and established firms (Messina et al., 2022).

Universities partake in the innovation process by exploiting basic and applied research to develop useful products or technologies for the society. Likewise, universities should integrate either directly or indirectly with industries on innovative products developed in the public or private sectors (Fasi, 2022). The TC process needs to be given close attention by the universities to successfully develop and commercialize new technologies (González et al., 2018). Nonetheless, success on this path is challenging since several commercialization-related constraints, as well as obstacles, have led to failure of commercialization (Meijer et al., 2019).

Universities can use distinct features (incubators, technology startups, and spin-offs), collective media (joint ventures, and strategic collaborations), and third parties to accomplish TC through sales, exchanges, technology transfer, and licensing (Kirchberger and Pohl, 2016). University commercialization centers (UCCs) such as Technology Transfer Offices (TTOs) are mostly situated in most universities to oversee the TC process (Sutopo et al., 2022). The UCCs are designed to foster the registration as well as the commercialization of valuable innovations for businesses, governments, and societies (González et al., 2018).

2.2. Factors that influence TC

The factors (extrinsic and intrinsic) that influence the success of TC need to be addressed by an organization while defining its goals or scopes. Identifying the success factors that influence the performance of TC in different organizations is critical for analyzing the organizational resources, policies, and environments (Yazdimoghaddam et al., 2019). The identification of these factors must be based on the industries, technologies, and organizations so that the crucial factors can aid in decision-making, prioritization of factors, and development of evaluation models (Yazdimoghaddam et al., 2018).

Some of the factors that influence TC have been acknowledged in the literature over the last few decades. Due to the lack of agreement regarding the criteria that influence the success of TC, some researchers such as Olawore et al. (2022), Noh et al. (2018), and Zemlickienė and Turskis (2020) stated that there might not be any universal success criteria due to varied products and industries.

Kliewe and Marquardt (2008) identified the hiring of qualified R&D personnel, networking, intellectual property protection, flexible architecture, and creating market attention as the key factors that influence the success of commercializing software products. The success factors that influence the commercialization of information technology services were investigated by Park et al. (2017). The customers' needs, strong business strategies, capital investment, technological competitiveness, network support, marketing, as well as regulatory policy were identified as success factors for these services in Korea.

Cho and Lee (2013) pinpointed the success factors of commercializing new products. These criteria have 4 dimensions namely; technical competitiveness, marketability, R&D capabilities, and business feasibility. Hsu et al. (2015) examined the relevant criteria that impact university's technology transfer and commercialization success in Taiwan. These dimensions include human, cultural/institutional, financial, as well as commercial resources. VIKOR method was applied by Shu et al. (2023) for the analysis and prioritization of the performance factors on the commercial feasibility of energy storage technologies by assigning objective weights with the entropy weights method.

In another study, Yazdimoghaddam et al. (2019) determined the elements that influence TC success with their relative weight to build a scoring model for evaluating TC. The literature review and fuzzy Delphi technique were used to identify 32 factors which were classified under 4 dimensions namely; rules and confirmations, technological, financial, and market requirements. Similarly, the criteria that influence the potential of new product development projects for TC were identified by Jou and Yuan (2015). They identified 5 dimensions (market, risk, technology, business, and organization aspects) and 19 criteria based on a literature analysis and fuzzy Delphi assessment.

The criteria that influence the success of TC were also reviewed by Olawore et al. (2022) and the study was deduced with 5 dimensions (technology, market, organizational, financial, and societal) with 25 factors. However, literature review on the factors that influence the success of commercializing software products and other related information technology is limited. The initial factors obtained from the study of Olawore et al. (2022) were based on diverse technologies, industries, and organizations. However, the final collection of factors was streamlined based on criteria with similar functions or traits and focused on the TC of software products in higher education institutions (HEIs). Table 1 gives an overview of the factors obtained initially from previous studies and how they were coded to the finalized factors.

Prioritization of these success factors is important for an effective and efficient decision-making process. Several MCDM techniques such as analytic network process (ANP) (Hsu et al., 2015; Yazdimoghaddam et al., 2019), fuzzy AHP (Cho and Lee, 2013; Jou and Yuan, 2015; Lee et al., 2016), AHP (Park et al., 2017), and the integrated Fuzzy Delphic–Eckenrode Likert-type Scale-based Rating Technique (IFDELSRT) (Zemlickienė and Turskis, 2022b) have been adopted by researchers to evaluate the relative weights of the factors that affect the success of TC. However, the problem of inconsistency is one of the drawbacks associated with these MCDM methods. Thus, a new model called fuzzy BWM was introduced to address this inconsistency in a fuzzy environment (Goldani and Kazemi, 2023). Moreover, to the best knowledge of the authors, fuzzy BWM has not been applied to determine the priority of the factors and there is limited research that has studied the factors that influence the performance of TC for software products in universities.

3. Methodology

This section briefly describes the fundamental concepts of fuzzy BWM and the steps involved in determining the weights of the factors using fuzzy BWM.

3.1. *Fuzzy best worst method*

This approach uses fuzzy set theory to address the features of vagueness and ambiguity. It is more consistent than the fuzzy AHP approach and requires fewer comparison data (Pezeshkan and Navid, 2020). Several versions of fuzzy BWM have been developed by researchers. Guo and Zhao (2017), Khanmohammadi et al. (2019), and Mohtashami (2021) have employed fuzzy BWM which involves the combination of BWM and triangular fuzzy number (TFN) to determine the weights of the criteria and their relative importance. Also, Emamat et al. (2023a), Hosseini Dehshiri et al. (2022), and Emamat et al. (2023b) applied different forms of grey BWM to evaluate the criteria weights in their research.

However, Xu et al. (2021) applied the method used in their study by incorporating fuzzy preference relations (FPRs) into BWM to address the problems of ambiguity and uncertainty that are encountered in the actual world. The advantages of Xu et al. (2021)'s model are:

(i) It requires less computational effort.
(ii) The integration of FPRs into BWM makes it more straightforward for decision makers to give their comparisons.
(iii) It has lesser comparison data.

BWM determines the magnitude of preference between two options using Saaty's scale of 1–9. Fuzzy BWM, in contrast to BWM, is based on fuzzy preference values which employ a 0.5–0.9 scale to execute fuzzy preference comparisons, thereby making the analysis simpler and easier for decision-makers to present their comparisons. The basic concepts of FPRs and fuzzy BWM are explicitly explained by Xu et al. (2021).

The fuzzy BWM technique used in this study was in accordance with the methodology described by Xu et al. (2021). Figure 1 depicts the typical computation procedures for evaluating the weights of the factors using fuzzy BWM (Xu et al., 2021).

4. Data collection

4.1. *Refinement of the success factors*

The Delphi technique was used to analyze these factors in 3 stages. Questionnaires were issued to 12 experts (7 academics and 5 industrial experts) in the first stage of the Delphi approach to assess the suitability, applicability, and definition of the selected success factors (from the literature review) that influence the development and commercialization of a software product in HEI. Twelve experts were selected based on the recommendation of researchers that a group of 10–15 experts can be used for a Delphi study in order to achieve a timely and efficient conclusion (Hsu et al., 2015; Namdarian & Ali, 2018; Profillidis and Botzoris, 2019). The profiles of the experts are provided in Table 2.

Each expert was informed about the feedback of other experts and provided with a new questionnaire for further evaluation of the factors

Table 1
Overview of factors obtained from the literature review.

Final factor	Antecedent factors
R&D capability	Number of researchers, hiring of qualified R&D personnel, team structure, traits of individual, quality of research, new product development
Networking	Alliance formations, intermediaries support, networking activities, academic network, network support
Funding	Financial status, resources availability, cost of investment, capital return strategy, capital investment
Marketing	Creating market attention, perception of technology
Intellectual property protection	Legal rights, licensing strategies, patentability of technology, regulatory policy
Knowledge-sharing culture	Knowledge absorptive capacity, training of personnel, knowledge exchange
Distinctive features	Technical features, flexible architecture, acceptability of products
Entrepreneurial capability	Market potential, risk management, spin-out formation

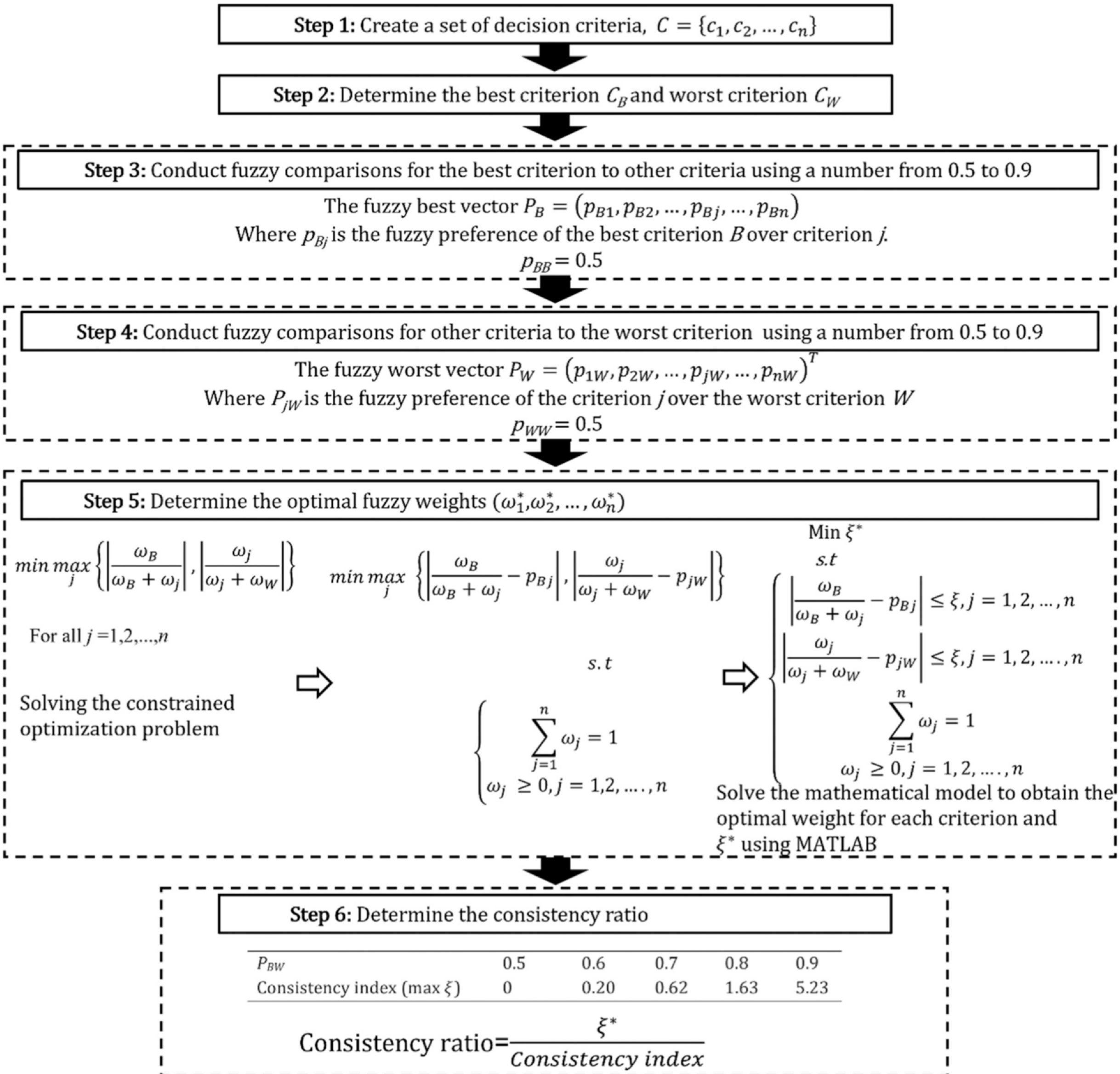

Fig. 1. The steps involved in evaluating the weight of each criterion using fuzzy BWM (extracted from Xu et al., 2021).

(Profillidis and Botzoris, 2019). The refinement of the factors was done by including and /or eliminating some of the factors suggested by the experts until a consensus was reached among the experts after the 3 stages.

In the first stage of the Delphi study, the experts suggested that supporting infrastructure, degree of technological complexity, technology suitability, testing the potential of a product to penetrate the market, the existence of supportive rules for TC, originality of a product, incentives for the developers and non-developers, identifying the present needs of the market, and ease of being copied or reproduced should be included among the factors.

Subsequently, the experts considered factors like the degree of technological complexity, technology suitability, and originality of a product to be under distinctive features of a software product. Identifying the present needs of the market and testing the potential of a product to penetrate the market were eliminated and considered to fall under the entrepreneurial capability criterion. The supporting infrastructure was excluded from the list of factors because it was considered as part of the expenditure incurred during software development. Thus, the funding criterion was considered to cater for the supporting infrastructure and resources. The intellectual property protection was considered to encompass the existence of supportive rules for TC and ease of being copied or reproduced. The incentive for employees (developers and non-developers) was agreed to be included among the factors that influence the development and commercialization of a software product. The criterion was rephrased as “motivational aids” and defined as provided in Table 3. Also, some grammatical errors in the definition of the criteria in Table 3 were corrected by the experts.

The factors and their definitions in relation to the development and commercialization of software products in HEIs, that were obtained after the Delphi study are listed in Table 3.

5. Results and discussion

5.1. Fuzzy BWM

The best criterion and worst criterion were selected by 5 experts that participated in the Delphi study. The best criterion was selected as the entrepreneurial capability by 4 experts whereas the remaining expert chose funding as the best criterion. Also, the 5 experts selected knowledge-sharing culture as the worst criterion. The fuzzy best vectors and fuzzy worst vectors obtained from the 5 experts were solved using

Table 2
The profile of the experts that participated in the Delphi study.

Type	Qualification	Job position	Department	Years of experience	Number of products commercialized	Publications related to technology management
Academic	PhD	Associate Professor	Computer Science	14	9	7
Academic	PhD	Associate Professor	Industrial Engineering	12	0	6
Academic	PhD	Senior Lecturer	Industrial Engineering	7	1	4
Academic	PhD	Professor	Entrepreneurship and Innovation Management	15	8	14
Academic	PhD	Senior Lecturer	Industrial Engineering	8	0	4
Academic	PhD	Reader	Technology Management	10	0	11
Academic	PhD	Director	Innovation and Technology Policy	9	8	6
Industrial	PhD	Assistant Director	Technology Acquisition, Research, and Commercialization	10	12	3
Industrial	MSc	IP Officer	Intellectual Property and Technology Transfer	9	3	2
Industrial	MSc	Assistant Director	Technology Management	12	10	7
Industrial	MEng	Software Developer	Information and Communication Technology	10	7	0
Industrial	BSc	Software Developer	Software Engineering	7	12	0

the steps highlighted in Figure 1. The weight of each criterion was obtained by solving the mathematical model using MATLAB based on the outcome of preference comparisons that were provided by the 5 experts.

The outcomes of the study (the optimum weights of the criteria and the consistency ratios (CRs) of the analysis) are provided in Table 4. The average weights of the criteria using fuzzy BWM are depicted in Figure 2. According to these findings, the most important and least important criteria for successful TC of software products in HEIs are entrepreneurial capability and knowledge-sharing culture, respectively. The orders of priority of the criteria from the most important to the least important are entrepreneurial capability, funding, R&D capability, networking, marketing, distinctive features, intellectual property protection, motivational aids, and knowledge-sharing culture.

The entrepreneurial capability of an organization is the major driver of business performance, especially when it involves integrating digital information based on innovativeness, proactiveness, and risk-taking ability in business processes (Lindholm-Dahlstrand et al., 2019). It involves the capabilities of a university to evaluate and convert the market potential of a software product into viable economic values by exploiting business opportunities in a market. University's entrepreneurial decisions indicate its entrepreneurial stance, which is exemplified by the degree to which employees have the propensity to take business-related risks, support new product development, and proactively seek out opportunities to gain a competitive edge for the university. Entrepreneurial abilities foster economic growth whilst also contributing to the success and productivity level of a university. It quickens the pace of innovation and job prospects, hence boosting a university's competitiveness (Crudu, 2019). Cho and Lee (2013) found that market potential (a subset of entrepreneurial capabilities) is the most critical factor for TC.

Muizniece (2021) affirmed that developing an entrepreneurial culture in an organization provides the gateway to monetary support and encourages researchers to engage in collaborating with the industry to develop software products. Funding is a critical criterion that contributes enormously to the development and commercialization of a software product via a UCC. Hsu et al. (2015) also revealed that funding is one of the most important factors for TC. It provides inputs such as supporting infrastructures and grants from financial organizations and government agencies, all of which are crucial to the development and commercialization of products (Oyebola et al., 2018). Furthermore, the costs of technology deployment, operations, maintenance, and marketing must be considered for effective TC of software products to take place (Bandarian, 2007).

R&D capability is the next important criterion in developing and commercializing software products. In terms of technical efficacy, the availability of research centers and competent R&D professionals have a positive impact on the evolution of technology innovation (Park and Shin, 2017). However, the R&D capability is one of the least important factors in the study of Cho and Lee (2013). It is noteworthy to point out that Cho and Lee (2013) conducted their research on machinery industries and the prioritization of the criteria might differ due to diverse sectors, products, and industries.

Networking activities between HEIs and industries via collaboration are also crucial to the successful development and commercialization of software products. Javaid et al. (2022) also ranked the creation of university-industry collaboration (UIC) as one of the important factors for successful TC. UIC is related to the sharing and transferring of information and technology, and it is important to the development of global economies as well as the competitiveness of organizations (Pujotomo et al., 2023).

Marketing is one of the important factors for commercializing a software product in a university. Yazdimoghaddam et al. (2019) also revealed that marketing is one of the important factors for TC. The marketing criterion assists universities by not only promoting and analyzing the needs of the market, but also by providing values to

Table 3
The factors obtained after the Delphi study and their definition.

Factors	Definition
R&D Capability (R&D)	This refers to the competence of the employees in an organization to develop a new software product or add new features to existing software products.
Networking (N)	This focuses on the collaboration between an organization and industries in the development and commercialization of a software product.
Funding (F)	This covers the amount of funding provided for the development and commercialization of a software product.
Marketing (M)	This signifies an organization's effort to promote and sell a software product to the end users.
Intellectual Property Protection (IPP)	It refers to the legal rights given to the developer to prevent imitation of a software product by other competitors.
Knowledge-sharing Culture (KSC)	This factor indicates an organization's culture to share, transfer and assimilate knowledge for developing and commercializing a software product.
Distinctive Features (DF)	This factor relates to the uniqueness of the features of a software product which supports or hinders its commercialization.
Entrepreneurial Capability (EC)	This refers to the capability of an organization to assess and transform the economic potential of a software product into achievable economic value by exploiting business opportunities in a market.
Motivational Aids (MA)	This refers to the rewards or incentives given to the personnel involved in developing and commercializing a software product.

Note: The term "organization" in Table 3 refers to a university or HEI.

Table 4
The optimal weights of the criteria and consistency ratios using fuzzy BWM.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average weight	Ranking
R&D	0.1338	0.0978	0.1578	0.1321	0.1276	0.1298	3
N	0.1338	0.1227	0.1004	0.1026	0.1020	0.1123	4
F	0.1336	0.1526	0.1578	0.2725	0.1539	0.1741	2
M	0.1055	0.1227	0.1004	0.0798	0.0811	0.0979	5
IPP	0.0665	0.0759	0.0785	0.0610	0.1020	0.0768	7
KSC	0.0444	0.0407	0.0421	0.0387	0.0477	0.0427	9
DF	0.0665	0.0978	0.0631	0.0798	0.1017	0.0818	6
EC	0.2495	0.2288	0.2367	0.1727	0.2167	0.2209	1
MA	0.0665	0.0610	0.0631	0.0610	0.0672	0.0638	8
ξ	0.0510	0.0510	0.0510	0.0264	0.0806		
CR	0.0098	0.0098	0.0098	0.0051	0.0154		

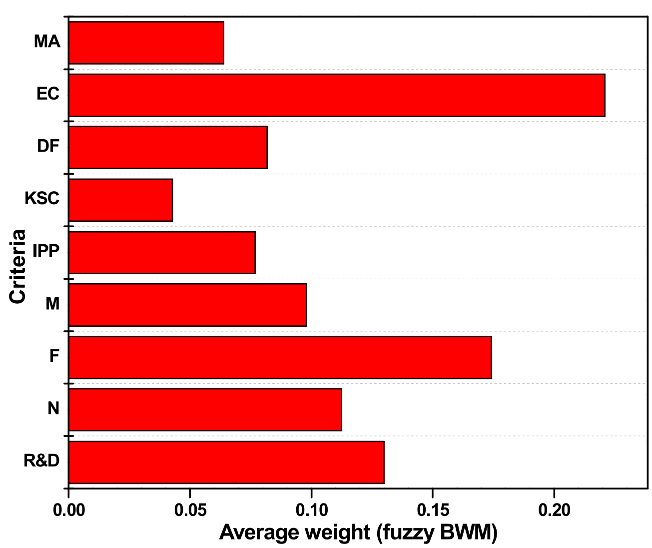

Fig. 2. The average weight of the criteria using fuzzy BWM.

existing and new software products, as well as meeting the customers' needs via marketing tactics, and niche identification (Arunachalam et al., 2018). Marketing strategies are used to enhance market and consumer acceptance of products through advertisement strategies, distribution network strategies, competitive advantages, and market infiltration tactics (Taweesangrungroj et al., 2021).

In this research, the knowledge-sharing culture is the least important criterion. Kumar et al. (2015) found that training and development support was ranked 13th spot out of 22nd critical factors. The managerial and strategic issue which encompasses the training and development support, commitment, personal resources, and strategic implications was prioritized as the least important dimension. However, the fuzzy environment was not considered by Kumar et al. (2015) in the application of AHP for ranking the criteria factors that influence technology transfer. It is imperative to note that adequate education, training, capacity building, and knowledge are needed for the workforce to ensure seamless operations with the latest technologies. knowledge-sharing culture involves the dissemination of information or knowledge for the development and commercialization of a software product. The exchange of knowledge can be in the form of intellectual discourses, conferences, workshops, and training on R&D and entrepreneurship that are organized or sponsored by a university for their employees.

5.2. Comparison with FAHP

In fuzzy AHP analysis, additional pairwise comparison data of the criteria were collected from the same 5 experts mentioned earlier. The subjective pairwise comparison data from the experts' decisions were presented in a linguistic form and subsequently transformed into TFNs. The geometric mean approach was applied to evaluate the weights and ranks of the factors that influence the successful commercialization of software products in HEIs. Figure 3 summarizes the steps for evaluating the weights of the factors and the consistency ratios.

The greater the value of the normalized weight, the higher the prioritization (ranking) of each criterion. Entrepreneurial capability and knowledge-sharing culture were discovered to have the highest and lowest priority respectively. As a result, EC and KSC are ranked first and ninth respectively as indicated in Table 5.

Figure 4 shows the average weights of the criteria using fuzzy AHP. The order of ranking from the most important criterion to the least important criterion is entrepreneurial capability, funding, R&D capability, networking, marketing, intellectual property protection, distinctive features, motivational aids, and knowledge-sharing culture.

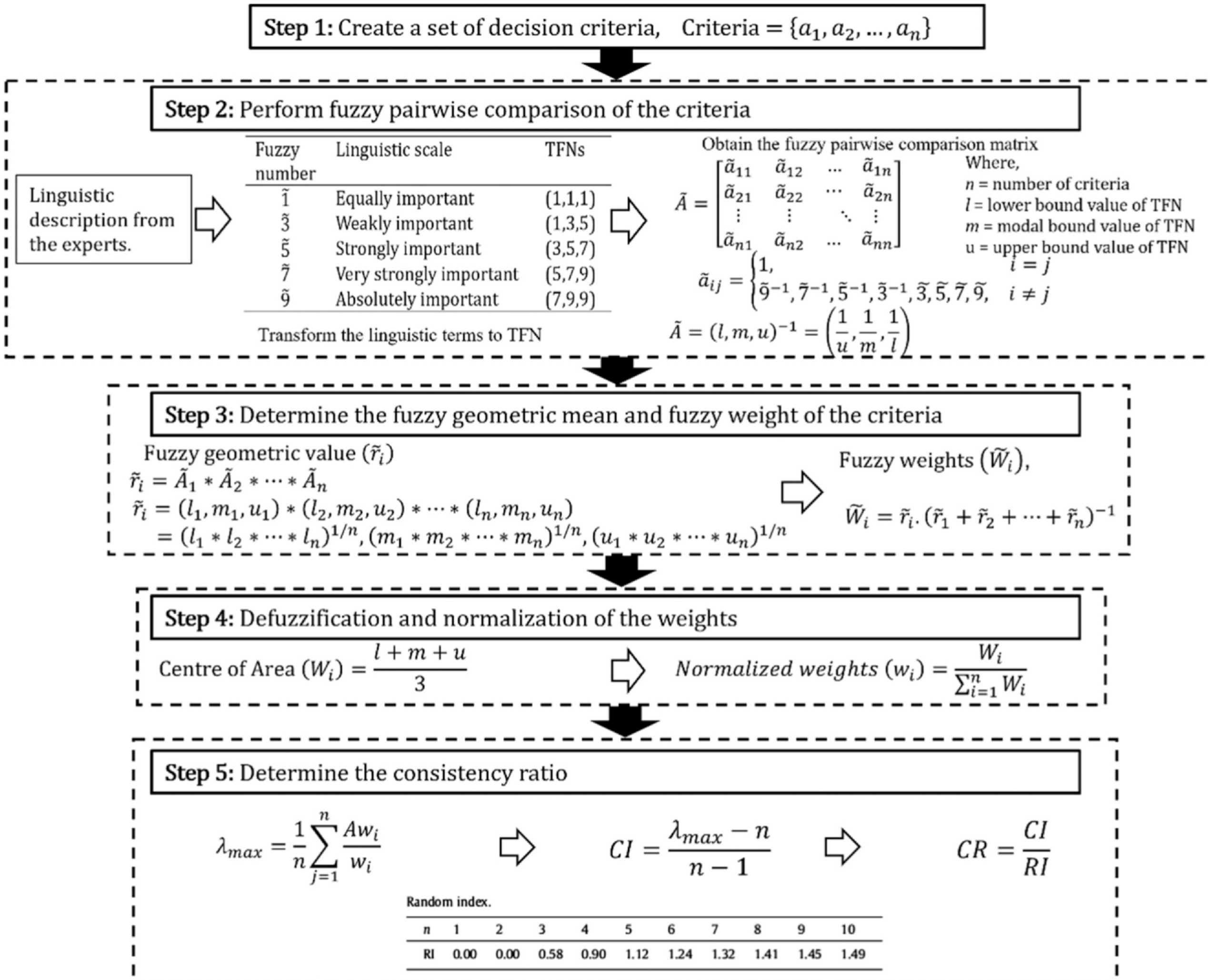

Fig. 3. The steps involved in evaluating the weight of each criterion using fuzzy BWM (extracted from Xu et al., 2023).

Figure 5 compares fuzzy BWM and fuzzy AHP in terms of the consistency of each expert's evaluation. The results show that the consistency ratios using fuzzy BWM are better when compared to fuzzy AHP for each expert. The consistency ratio value for fuzzy BWM for each expert is lower. Thus, fuzzy BWM is more consistent than fuzzy AHP and requires fewer comparison data (Pezeshkan and Navid, 2020).

Figure 6 summarizes the outcomes of examining the responses of the experts to determine the optimal weights of the criteria by applying fuzzy BWM and fuzzy AHP. The comparative analysis of the outcomes for the two MCDM methods indicates that the rankings of the criteria are the same except for the changes between the sixth and seventh criteria. It is noteworthy that distinctive features and intellectual property protection work in synergy and contribute to the success of TC in HEIs.

Intellectual property protection emboldens technology developers to protect their new software products with distinctive features from being imitated by other competitors as well as to acquire property rights of their new software products. The distinctive features of a product influence the market potential by identifying prospective users owing to specific preferences for particular technological traits such as

Table 5
The optimal weights of the criteria and consistency ratios using fuzzy AHP.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average weight	Ranking
R&D	0.199	0.141	0.162	0.155	0.165	0.164	3
N	0.172	0.107	0.122	0.116	0.114	0.126	4
F	0.130	0.216	0.204	0.287	0.218	0.211	2
M	0.111	0.045	0.104	0.075	0.081	0.083	5
IPP	0.066	0.080	0.058	0.038	0.048	0.058	6
KSC	0.019	0.019	0.018	0.018	0.015	0.018	9
DF	0.038	0.060	0.047	0.059	0.041	0.049	7
EC	0.265	0.305	0.258	0.222	0.293	0.269	1
MA	0.030	0.027	0.026	0.030	0.025	0.028	8
λ_{max}	10.058	10.063	9.816	10.004	10.112		
CI	0.132	0.133	0.102	0.126	0.139		
CR	0.091	0.092	0.070	0.087	0.096		

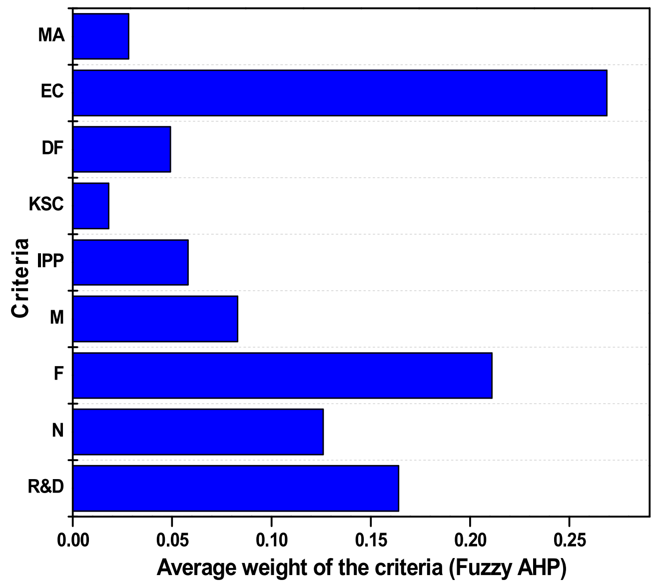

Fig. 4. The weights of the criteria using fuzzy AHP.

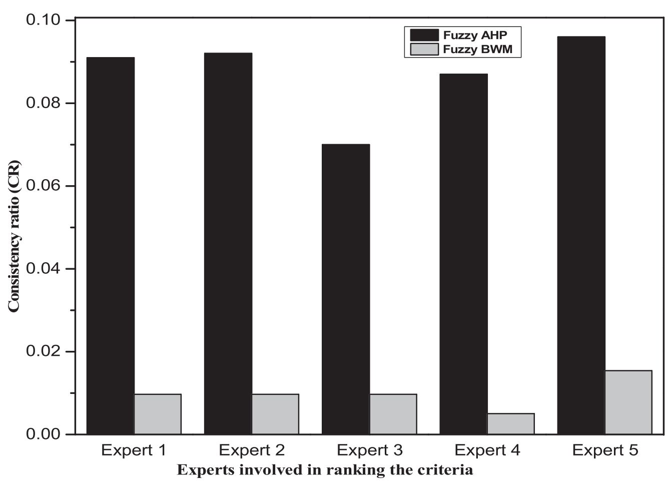

Fig. 5. Comparative analysis of the consistency ratios for the applied MCDM methods.

the genericness, innovativeness, compatibility, and intricacy of the product (Chen et al., 2011). These features inspire the potential end-users to accept and patronize the software products that suit their perceived needs in the aspects of functionality, originality, and reliability (Chiș and Crișan, 2020).

The difference in subjectivities among the experts could be a factor contributing to the disparity in the ranking of the criteria. Personalities with different or comparable work profiles make different decisions based on their diverse educational, cultural, economic, social, as well as demographic backgrounds. Nevertheless, distinctive features and intellectual property protection operate in synergy for a developed software product to be successfully commercialized. The distinctive features of the product can encourage the software developer to apply for intellectual property protection to prevent other competitors from replicating it. In general, the two MCDM techniques offered identical outcomes, with the exception in the sixth and seventh spots.

This research provides a new set of prioritized factors that is specifically relevant for the development and commercialization of software products in UCC. The uniqueness of entrepreneurial capability as the most important factor in UCC showcases the importance of encouraging academics to actively participate in entrepreneurial activities and take risks similar to their industrial counterparts. It emphasizes the need for academics to promote risk-taking during problem-solving and to successfully introduce software products for market adoption. Knowledge-sharing culture is considered as the least important factor despite the responsibilities saddled by universities to disseminate knowledge. Academics have inherent knowledge and easy access or exposure to training and education, unlike the experts in industries that expend huge resources on education, capacity building, and training of their personnel. Also, social media have eased the sharing of knowledge in the form of intellectual discourses, conferences, workshops, and trainings on R&D and entrepreneurship.

6. Implications of the research

Theoretically, this research gives insights to researchers in analyzing the factors (with their degree of importance) that influence the success of developing and commercializing software products in HEIs. Moreover, it will also spur researchers to develop a model to assess the performance of TC in HEIs before implementation to eschew depletion of resources, unsuccessful commercialization projects, and non-productive investments. This research provides a realistic checklist of

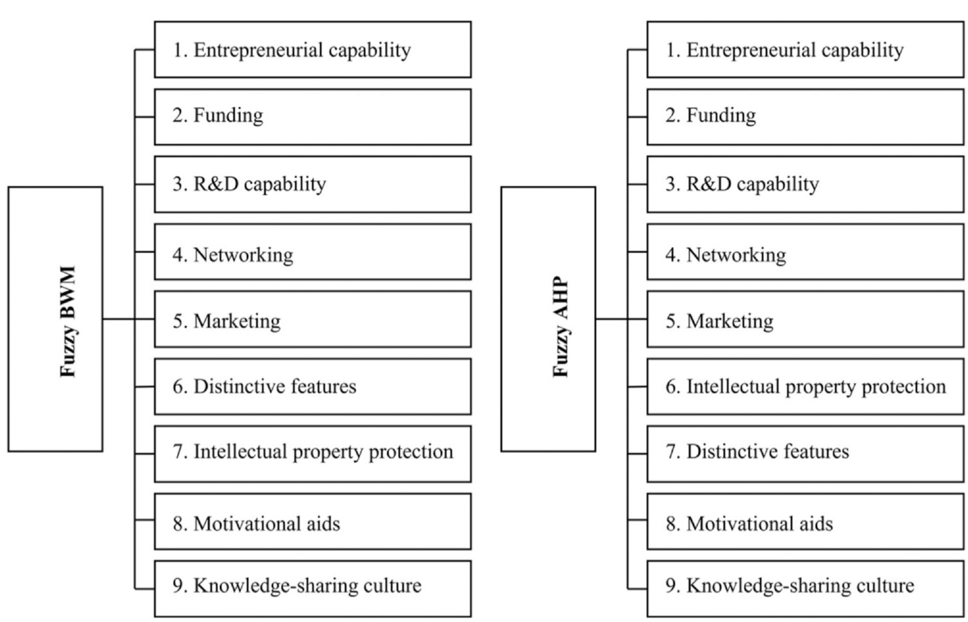

Fig. 6. Comparative illustration of the rankings using fuzzy BWM and fuzzy AHP.

factors to be followed in UCCs and aids the beneficiaries (academics, researchers, entrepreneurs, and decision-makers) to allocate resources appropriately based on the order of priority of the criteria.

Practically, this research provides a platform for decision-makers to judge explicitly the level of TC in their university with solid measures and criteria rather than intuition or gut feeling to measure the entrepreneurial disposition of their university. The prioritization of the criteria will aid decision-makers in analyzing their organizational resources, policies, and environments for commercialization. It will also aid time-sensitive decision-making and minimize errors in developing and commercializing software products in HEIs. Lastly, the TC factors or criteria will aid the policymaker or government in deciding which UCCs or entrepreneurs should be supported, and to what extent.

7. Conclusions

This study evaluated the prioritization of the success factors that influence the TC of software products in HEIs. A literature review and Delphi study were applied to identify the criteria. The criteria were prioritized using fuzzy BWM and validated using the fuzzy AHP method via comparison. The most important criterion and least important criterion from both methods are entrepreneurial capability and knowledge-sharing culture respectively. The orders of priority of the criteria from the most important to the least important as obtained from fuzzy BWM are entrepreneurial capability, funding, R&D capability, networking, marketing, distinctive features, intellectual property protection, motivational aids, and knowledge-sharing culture. The comparative analysis of the outcomes for the two MCDM methods indicated that the rankings of the criteria are the same except for the changes between the sixth and seventh criteria. It is noteworthy that distinctive features and intellectual property protection work in synergy and contribute to the success of TC in HEIs. The difference in subjectivities among the experts based on their diverse social, educational, and cultural backgrounds could be a factor contributing to this disparity.

This study contributes new knowledge to the identification of a set of factors and prioritization of these factors that influence the success of commercializing a software product in a university using fuzzy BWM. This research offers a practical checklist of factors to be considered by stakeholders in UCCs such as academics, researchers, entrepreneurs, and decision-makers in effectively allocating resources according to the prioritized order of the criteria.

This research has certain limitations as it relies on the knowledge and expertise of a specific group of experts, which may not necessarily reflect the perspectives of the end users. Also, this study does not delve into analyzing the interconnections among the factors. However, comprehending these relationships is crucial for identifying the factors that facilitate TC performance.

Future studies can consider conducting expert and consumer surveys to further explore and identify the factors that play a role in the successful commercialization of software products across various organizations. Researchers also need to focus on using other MCDM techniques to prioritize the factors for comparative analysis. This analysis can also be extended to different sectors and industries. Lastly, future research can apply the identified criteria as the inputs in the development of a quantitative model for the evaluation of TC performance using suitable machine learning methods.

Ethical Statement

Not applicable because animal and human subjects were not applied for the study.

Data Availability

The data used in this study are available on request from olawore@graduate.utm.my

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgements

The authors would like to acknowledge the financial support from Universitas Sebelas Maret, Indonesia under the Matching Grant Scheme with Universiti Teknologi Malaysia (R.J130000.7351.4B679 and Q.J130000.3051.03M62).

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