OPEN ACCESS Int. J. Agr. Ext. 09 (03) 2021. 533-557 DOI: 10.33687/ijae.009.03.3686

Check for updates

Available Online at EScience Press
**International Journal of Agricultural Extension**
ISSN: 2311-6110 (Online), 2311-8547 (Print)
https://esciencepress.net/journals/IJAE

# TRENDS IN THE USE OF MULTI-CRITERIA DECISION-MAKING METHODS IN TECHNOLOGY TRANSFER PROCESSES (A CRITIC REVIEW)

[a]**William A. Orjuela-Garzon***, [b]**Santiago Quintero**, [c]**Mauricio U. Maldonado**
[a] *School of Engineering, Universidad Pontificia Bolivariana, Medellín 050031, Colombia.*
[b] *Industrial Engineering Faculty, School of Engineering, Universidad Pontificia Bolivariana, Colombia.*
[c] *Department of Industrial and Systems Engineering, Federal University of Santa Catarina, Colombia.*

**ARTICLE INFO**

**Article History**
Received: July 21, 2021
Revised: October 29, 2021
Accepted: September 14, 2021

**Keywords**
Technology transfer
Decision making
Trends
Uncertainty
Multi-criteria
Multi-attribute
Multi-objective

**ABSTRACT**

The application of multi-criterion decision-making methods allows reducing the ambiguity, imprecision, uncertainty, and subjectivity in human-based judgments when processes of transfer and appropriation of technologies are developed. These types of MCDM are key for developing countries since the efficiency of the transfer process is vital to improve the productivity and competitiveness of companies and territories based on correct prioritization and selection of technologies, the definition of barriers and drivers, or the selection of the best provider, among others. In this sense, it is key to identify what is the evolution in the empirical use of this type of techniques for knowledge management and the reduction of competitive gaps. The objective of this review was to identify the current state-of-the-art of applications and use of methods for multi-criteria decision-making process in sectorial technology transfer, to establish trends, application areas, and future challenges. The review was conducted in the "SCOPUS" database between the years 2010 through 2021. The results showed three major research perspectives: a) Determination of technology-transfer strategies, b) Selection of appropriate technologies and c) Determination of barriers and drivers. The correct selection of transfer strategies and appropriate technologies can improve the efficiency of sectors such as agriculture, renewable energies, manufacturing, and construction that still refuse to introduce innovations, due to barriers such as acquisition and maintenance costs, complexity of use, ease of use. use and perceived utility.

**Corresponding Author: William A. Orjuela*
*Email: william.orjuela@upb.edu.co*


## INTRODUCTION

In an environment of high uncertainty, rapid changes and high speed in the development of industrial goods and products, technology has been considered a crucial factor in the development of competitive advantages for many organizations (Dinmohammadi and Shafiee, 2017). The acquisition of key technology is especially important for the manufacture of advanced products, and the Know-How of the technology must be completely transferred to the user to allow efficient use of it (Lee *et al.*, 2010), and thus obtain the expected results in terms of productivity, market, income generation and return on investment.

The selection of suitable technology, the identification of barriers and drivers, and the prioritization of a suitable supplier are critical stages for the development of successful technology transfer processes. Aliakbari Nouri *et al.* (2015), reason why the limited knowledge, the multiple variables that are in play, and the different actors that participate in the process present a high complexity. Multi-criteria decision-making methods (MCDM) have become a key tool to facilitate technology transfer (TT) processes key for developing countries, since their versatility has allowed the development of research processes around policymaking, the definition of transfer models, prioritization of technologies for countries and companies, identification of barriers and facilitators, and construction of efficient transfer strategies. This is the case of Vera-Montenegro *et al.* (2014) that Implemented a post-harvest technology selection model for Ecuador cocoa growers, considering the fermentation and drying stages (see Figure 1).

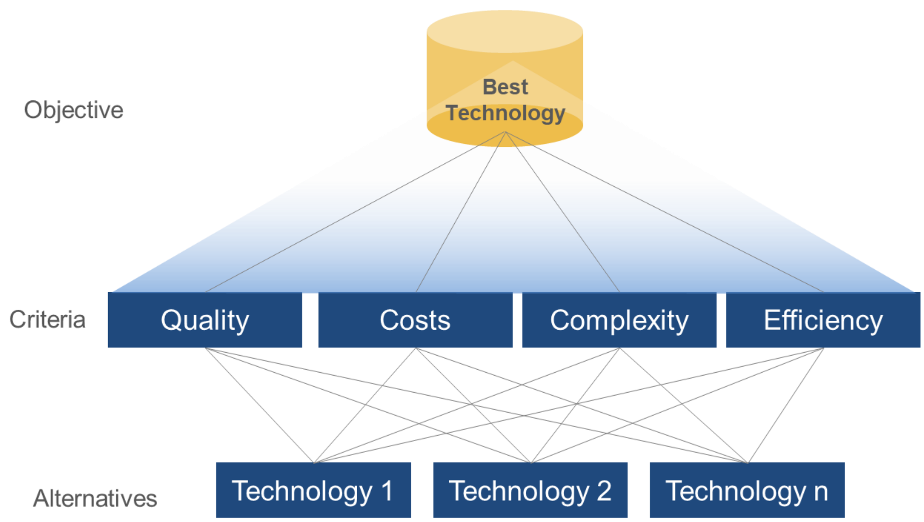


Figure 1. AHP structure for technology selection.

From this perspective, the objective of this work was to identify the current state of research regarding the application of MCDM in technology transfer processes, establishing current research trends, areas of application, and future challenges for this knowledge area. The review was conducted in the specialized SCOPUS database, based on the number of indexed journals from developing countries that have research related to the topic of search, and using a search algorithm that allowed obtaining academic documents relevant to the subject of study in the period 2010 to 2021, the selected references were processed through the Matheo Analyzer 3.2 software. Matheo Analyzer enables statistical analysis of various business information (patents, scientific papers, press releases, ...) coming from all structured data (more information: https://www.matheo-software.com/products/ ).

The document is organized in the following way, section two shows the theoretical framework applied to the study topic, in section three the methodological process followed for the systematic review of the literature is exposed, section four shows the results and the general findings of literature review process, section five shows the trends analysis and main factors and sub-factors that affect the performance of the transfer process and finally section six relates the conclusions of the exercise.

## Technology transfer and MCDM

### Technology transfer

Technology transfer has been defined as the adaptation process in which technology, knowledge, or information developed by a given organization for a specific purpose is applied for different purposes in different fields and by different organizations (Winebrake, 1992). Nowadays, technology transfer plays an important role in the development, productivity, and performance improvement of small and medium-sized companies in their effort towards globalization (Chehrehpak, 2012; Lee *et al.*, 2012) and competitiveness (Lee *et al.*, 2012). The complexity of the process itself lies in the identification, evaluation and prioritization of technology transfer processes and strategies, the foregoing due to the presence of different decision-makers, the qualitative nature of the process, and the existence of imprecision and uncertainty in the process of decision-making (Dinmohammadi and Shafiee, 2017).

### Transferor and Transferee

Technology transfer takes place in a setting where three elements are protagonists, recognizing that there are others: the transferor, diffuser, and the transferee. This makes the success or failure of the effectiveness of Technology Transfer difficult to assess due to its complex structure, which contains multiple dimensions from the transferor to the transferee, such as technology, culture, and people in organizations (Wen-Hsiang and Chien-Tzu, 2008). The transferor is the owner of the knowledge and the end-user of the knowledge is called the transferee, however, the simple fact that both exist does not imply that the transfer is carried out naturally and that communication channels and other elements are not required (Khabiri *et al.*, 2012). The more complex the technology, the greater the level of cooperation between the parties is required to improve the use of technology likewise, the attitude of the Transferor and Transferred, and the training services can support the transfer process since a positive attitude and the acquisition of knowledge can lead to success (Díaz-Díaz *et al.*, 2008).

### Technology transfer methods

TT is based on the appropriation, proliferation, promotion, and use of technical achievements within countries, regions, sectors, industries, or enterprises (Audretsch *et al.*, 2012), reason why Transferor-Transferee can take alternatives around obtaining this knowledge. Among them are: Reverse engineering, foreign license, turnkey, technology skills training (Dinmohammadi and Shafiee, 2017) Joint venture, Joint R&D, R&D Outsourcing (Servati, 2017) foreign direct investment, industrial espionage, technical assistance, franchising or exchange of human resources (Chehrehpak, 2012). Selection of any of these strategies will depend on factors such as the state of technology in the industry, the requirements, capabilities, methods, possibilities, and weaknesses of the technology, the state of technology in other countries, national strategies, etc. (Chehrehpak, 2012). Likewise, the lack of understanding, cultural differences, differences in philosophies and management styles, and less effective mutual communications generally cause problems during technology transfer (Wen-Hsiang and Chien-Tzu, 2008).

### Multi-criteria decision-making methods (MCDM)

MCDMs aims to support optimum decision-making when confronted with conflicting alternatives (Gwo-Hshiung and Jih-Jeng., 2011). Problems of this kind arise every day in daily life, for example, in the personal context, job selection may depend on company prestige, location, salary, growth opportunities, and working conditions, among others (Hwang and Yoon, 1981).
To achieve the goal expected by the decision process, two critical questions must be overcome: structuring preferences and factor weights (Gwo-Hshiung and Jih-Jeng., 2011), in effect, the purpose of selecting new technology or a new technological provider in real conditions should involve both quantitative and qualitative factors to be analyzed in the evaluation. MCDM problems can be classified into two main categories: Multi-attribute Decision-Making (MADM) or Multi-Objective Decision-Making (MODM), according to the purpose and data types (Gwo-Hshiung and Jih-Jeng., 2011; Hwang and Yoon, 1981).

### Multi-Attribute Decision-Making (MADM)

The historical origin of MADM can be traced from the correspondence between Nicolas Bernoulli (1687–1759) and Pierre Rémond de Montmort (1678–1719), discussing the St. Petersburg paradox (Hwang and Yoon, 1981). The distinctive feature of MADM is that there are a limited (and accounting for a small) number of predetermined alternatives. The alternatives have an associated level of achievement of the attributes (which may not necessarily be quantifiable) based on which the final decision will be made. The final alternative selection is made using comparisons between attributes and intra-attributes. Among the most used methods for technology transfer decision-making are: Analytical Hierarchy Process (AHP), Fuzzy analytic hierarchy process (FAHP), Fuzzy Analytic Network Process (FANP), and Fuzzy logic, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy TOPSIS, Fuzzy Delphi, System dynamics and Fuzzy set theory. Other small uses, but interesting methods include: Choquet Integral Based Multi-Criteria Assessment, and Simple Additive Weighting (SAW). Here is a brief description of each of these.

#### Analytical Hierarchy Process (AHP)

It is a research method that supports multi-qualified rational decision-making (Thomas L Saaty, 1971). This method can present flexible solutions to both qualitative and quantitative problems.

The method comprises 3 main steps, (i) development of the hierarchical structure of the problem in terms of general results, criteria, and alternatives, (ii) defining priorities through peer comparison and (iii) review of consistency so that the judgment is valid enough (Dinmohammadi and Shafiee, 2017).

### Analytic Network Process ANP

Analytical network process (ANP) was proposed by Saaty (1990) to extend the AHP and release the constraints from the hierarchical structure, indicating that the criteria are independent of each other. By raising the super matrix to limit powers, global priority vectors can be obtained with the specific network structure to determine dependency and feedback problems between criteria (Gwo-Hshiung and Jih-Jeng., 2011). ANP assesses the relationship between criteria and decision levels through network relationships (Aliakbari Nouri *et al.*, 2015).

### Fuzzy analytic hierarchy process (FAHP)

FAHP is a method based on an additive weighting process, in which multiple attribute weighting measurements are computed by pairwise comparisons of the relative importance of each pair of criteria (Saaty, 1990), However, fuzzy AHP can reflect the exact values of experts to fuzzy numbers in paired matrix comparison; therefore, it can solve hierarchical fuzzy problems (Lee and Chou, 2016).

### Fuzzy Analytic Network Process (FANP)

The key concept of ANP is that influence does not necessarily have a hierarchical structure, as is the case with AHP. Influence can flow between any factor in the network, causing non-linear results for the scenario choices priorities. In general, ANP models have two parts.

The first is a hierarchy of control or network of objectives and criteria that control interactions in the system under study. The second part consists of subnets of influences between problem elements and criteria, with one for each control criterion (Yung-Hsiang, 2012).

### Fuzzy logic

The term "Fuzzy Logic" emerged in developing fuzzy set theory (Zadeh, 1965). It uses "soft" language system variables and a continuous range of real values in the interval [0, 1], rather than strict binary assignments and decisions. Fuzzy logic is a powerful problem-solving theory with a myriad of applications in integrated control and information processing (Wen-Hsiang and Chien-Tzu, 2008).

### Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS was proposed by Hwang and Yoon (1981) to determine the best alternative based on the concepts of the compromise solution. The compromise solution can be considered to choose the solution with the shortest Euclidean distance from the ideal solution and the Euclidean distance further from the ideal negative solution (Gwo-Hshiung and Jih-Jeng., 2011; Thampi and Rao, 2015).

### Fuzzy TOPSIS

The Fuzzy TOPSIS method applies a hybrid approach, where the qualifications of the alternatives concerning the criteria are evaluated using linguistic variables. Language variables are represented by fuzzy numbers that are subject to additional calculations (Aliakbari Nouri *et al.*, 2015).

### Fuzzy Delphi

The Delphi method provides the ability to fully integrate the opinions of various experts, is time-consuming, costly, and has a lower questionnaire return rate as it tries to achieve convergent results through repetitive surveys (Shen *et al.*, 2010), in other words, as rounds continue, participating experts may take a long time to respond, delaying the process. Ishikawa *et al.* (1993) introduce the fuzzy Delphi method to avoid the above defects using fuzzy logic. Delphi's fuzzy method can converge expert responses with fewer survey rounds and effectively address its ambiguity and uncertainty.

### System dynamics - SD

A system is defined as a collection of elements that continually interact over time to form a unified whole. Dynamics refers to changes over time. It is, therefore, a methodology used to understand how systems change over time. SD is an approach to problem-solving initially developed in the late 1950s by Jay W. Forrester from the MIT Sloan School of Management with the establishment of the MIT Systems Dynamics Group (Forrester, 2007). It is a computer simulation tool to frame, understand, and discuss complex issues. (Azar, 2012)

Choquet Integral Based Multi-Criteria

A traditional multi-criterion combined assessment method that takes the additive concept as the basis for determining whether the criteria are independent of each other or not. In other words, using a multi-criteria combination evaluation to evaluate a system is a Simple Additive Weight (SAW) operation that summarizes individual criteria and values (Huang, 2012).

Simple Additive Weighting (SAW)

It is a method that multiplies normalized criteria values with greater importance, the alternative with the highest score is the one chosen (Thampi and Rao, 2015).

**Review planning**

To respond to the defined objective, a systematic review of the scientific literature was carried. The steps described below were tracked; it began with the definition of the search keywords associated with the research area, to proceed to the search in the SCOPUS database (Orjuela *et al.*, 2020). Three groups of keywords were created with terms with related meanings, shown in Table 1.

Table 1. Keywords for the search query.

| |
|---|
| Group 1 |
| "decision-making", "decision-support", "decision" |
| Group 2 |
| "multiple criteria", "multi-criteria", "multicriteria","multi-objective", "multiobjective”,"multi-attribute” “multiattribute" |
| Group 3 |
| "Transfer of technology", "technology transfer", "technology appropriation", "technology choice", "technolog* adoption", "technology acquisition" |

From these sets of words, a Query algorithm was designed for the SCOPUS database, a period of 10 years was considered, and the research fields chosen for the retrieval of the scientific literature were Title (Title), Abstract (ABS), Keywords (KEY) and publication period (PUBYEAR). The algorithm result is shown in Table 2.

Table 2. Query algorithm (((Group 1) AND (Group 2)) AND (Group 3)).

| |
|---|
| (( ( TITLE-ABS-KEY ( "decision-making" ) OR TITLE-ABS-KEY ( "decision-support" ) OR TITLE-ABS-KEY ( "decision*" )) AND ( TITLE-ABS-KEY ( "multiple criteria" ) OR TITLE-ABS-KEY ( "multi-criteria" ) OR TITLE-ABS-KEY ( "multicriteria" ) OR TITLE-ABS-KEY ( "multi-objective" ) OR TITLE-ABS-KEY ( "multiobjective" ) OR TITLE-ABS-KEY ( "multi-attribute" ) OR ( TITLE-ABS-KEY ( "multiattribute" ) ) )) AND ( TITLE-ABS-KEY ( "transfer of technology" ) OR TITLE-ABS-KEY ( "technology transfer" ) OR TITLE-ABS-KEY ( "technology appropriation" ) OR TITLE-ABS-KEY ( "technology choice" ) OR TITLE-ABS-KEY ( "technolog* adoption" ) OR TITLE-ABS-KEY ( "technology acquisition" ) ))AND PUBYEAR > 2010 |

To ensure the quality of the results, a manual review of each of the articles was performed and only those that met the following criteria of eligibility were selected:

- Is related to the central topic of study (technology transfer)
- Provides clear information about the multi-criteria decision method used.

Thus, results are reduced and the quality of sources that can be used to meet the study objective is guaranteed. These inclusion criteria were conducted in two stages, initially reviewing the abstract to verify compliance, and keep them on a waiting list, and then read them fully to decide whether to retain or discard them. Prioritized ones were analyzed manually, using the Matheo analyzer 3.2 software.

**Review development**

The protocol described in the preceding section was used to research, select, and analyze the scientific documents. For the search process, the algorithm defined in Table 2 was used in the SCOPUS database, this step allowed it to generate a list of 153 scientific documents.

The scientific documents were assessed to meet the criteria of eligibility (i) the scientific document is related to the central topic of study (technology transfer); and

(ii) the scientific document provides clear information about the multi-criteria decision method used. After excluding literature that did not meet the criteria, 67 scientific documents were selected (see Figure 2). Then the 67 scientific documents selected were analyzed in accordance with the aspects set out in Table 3.

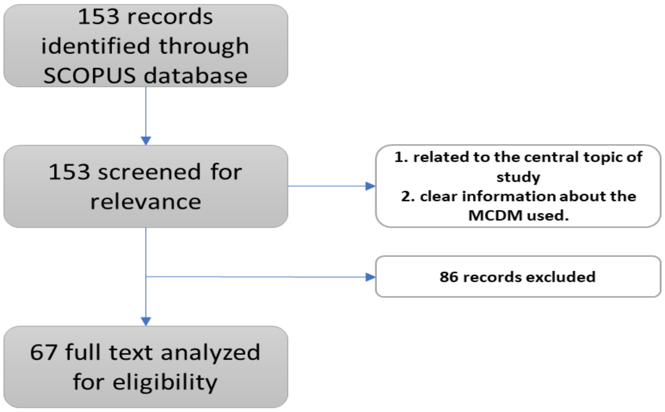


Figure 2. Literature review analysis process.

Table 3. Defined features for analysis.

| Field analyzed | Description |
|---|---|
| Year | Year of publication of the scientific paper |
| Publication Country | Country to which the researcher belongs |
| Country of implementation | The country in which the investigation was conducted |
| Source | Scientific document Source (Paper, Conference or Book Section) |
| Implemented method | Multi-criteria decision approach implemented in the study |
| Application area | Economic field or sector of application of the study |

Figure 3 shows the scientific production for the period 2010-2021, a permanent interest in this field of study is observed in this literature review, the years with the highest output were 2018, and 2020. Regarding countries where the investigations are conducted, Iran is observed as the leader with 10 investigations, one more than Taiwan (see Figure 4), countries from the Middle East, Southeast Asia and Asia have clear research focuses in the application of MCDM, and are the subjects of emerging technologies and advanced manufacturing due to their status as world leaders in different sectors like computing, transportation, and renewable energy.

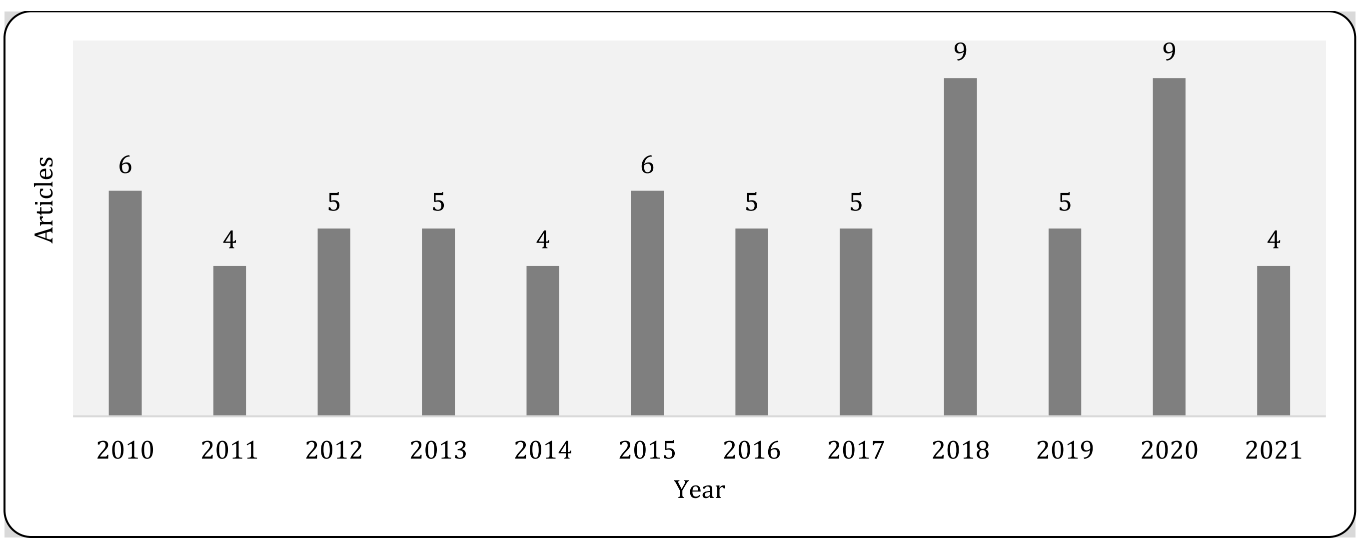


Figure 3. Annual scientific production for 2010-2021.

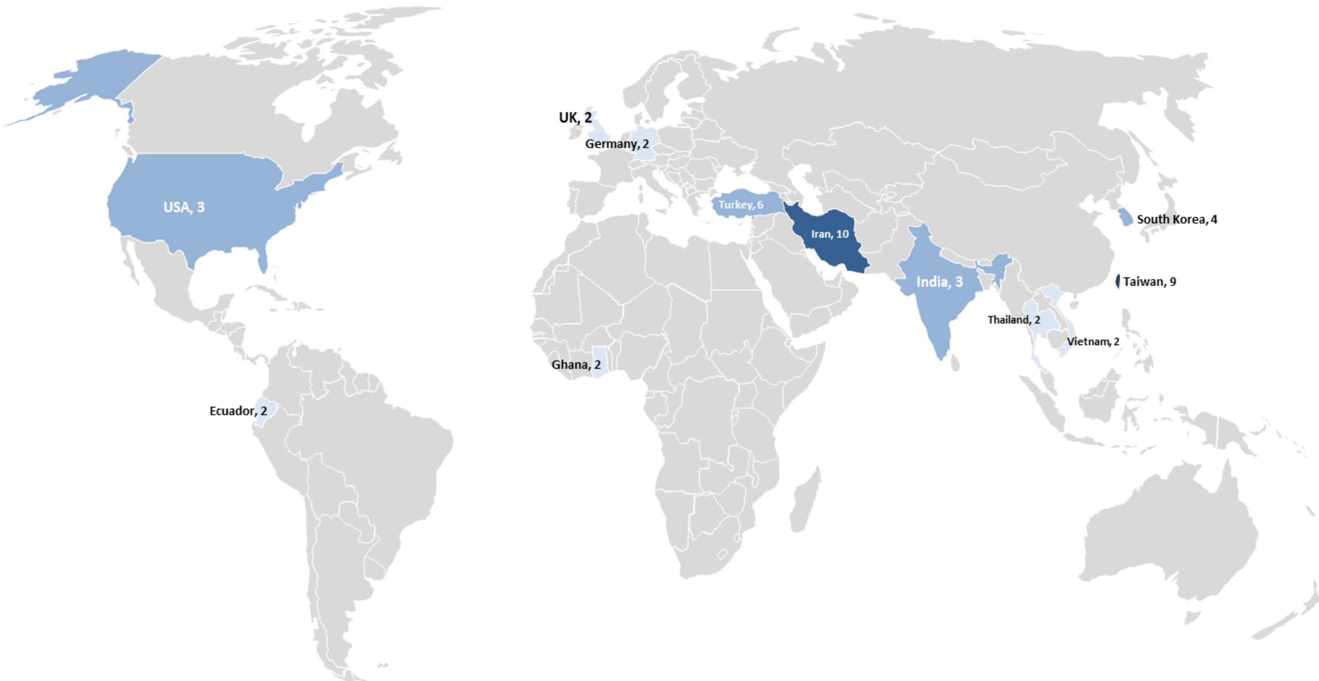


Figure 4. Scientific production by country.

As for the multi-criteria decision methods implemented in the development of research related to Technology Transfer, the most widely used and appropriate by researchers is the AHP Analytical Hierarchy method with 25 related scientific documents, the Fuzzy method also appears due to the ease they provide when making qualitative assessments by experts as shown in Figure 5. Finally, the highlighted areas or sectors of application are agriculture, renewable energy, and electronics. In the first area, research focuses on the use of multi-criteria methods to prioritize technologies and identify motivators for their choosing. Regarding renewable energy resources, this area focuses on prioritizing technologies for the generation of clean energy such as wind turbines and photovoltaics, and for the electronics area, the applications are diverse and are framed in areas of semiconductors, electric vehicles, and biosensors.

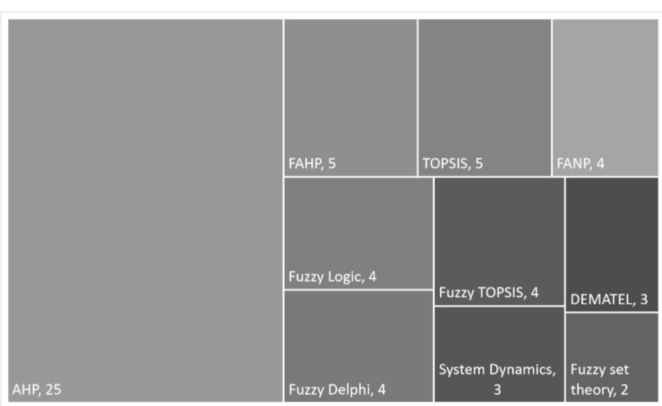


Figure 5. Multi-criteria decision method used.

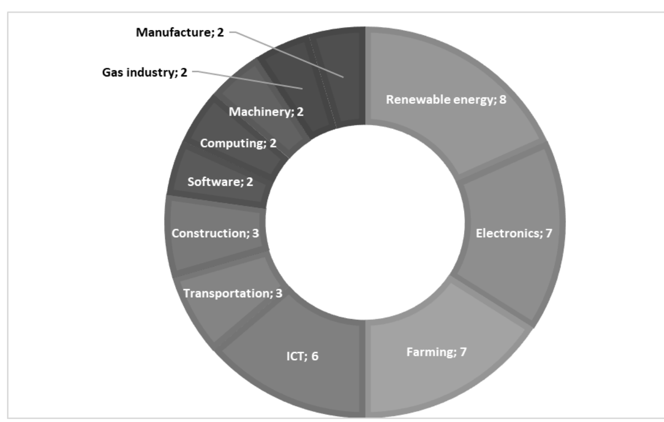


Figure 6. Application area of multi-criteria methods in technology transfer.

**Trend analysis**

Through the in-depth review of each of the 67 scientific documents and the use of the Matheo analyzer software, three major research trends and 10 sub areas around technology transfer were identified applying multi-criteria methods; these are: Determination of technology transfer strategies, selection of suitable technologies and determination of barriers/ drivers.

The determination of strategies focuses on the identification of the motivations and behaviors of the agents involved in the transfer of technology, as well as the selection and construction of transfer models and strategies adjusted to the specific requirements of the organization or the country. Another highlighted sub-area is research in the design of policies that support and facilitate the TT processes for the selection of technologies, it is a trend of high importance and application due to the contribution of effective MCDM, this is the reason the focus is the construction of hybrid selection models that combine both quantitative and qualitative evaluations at various stages by the experts. Finally, the focus of the trends around the identification of barrier /drivers are oriented to the prioritization of factors in different links of the value chain and the modeling of complex adoption and transfer scenarios, Figure 7 shows the tree full trend.

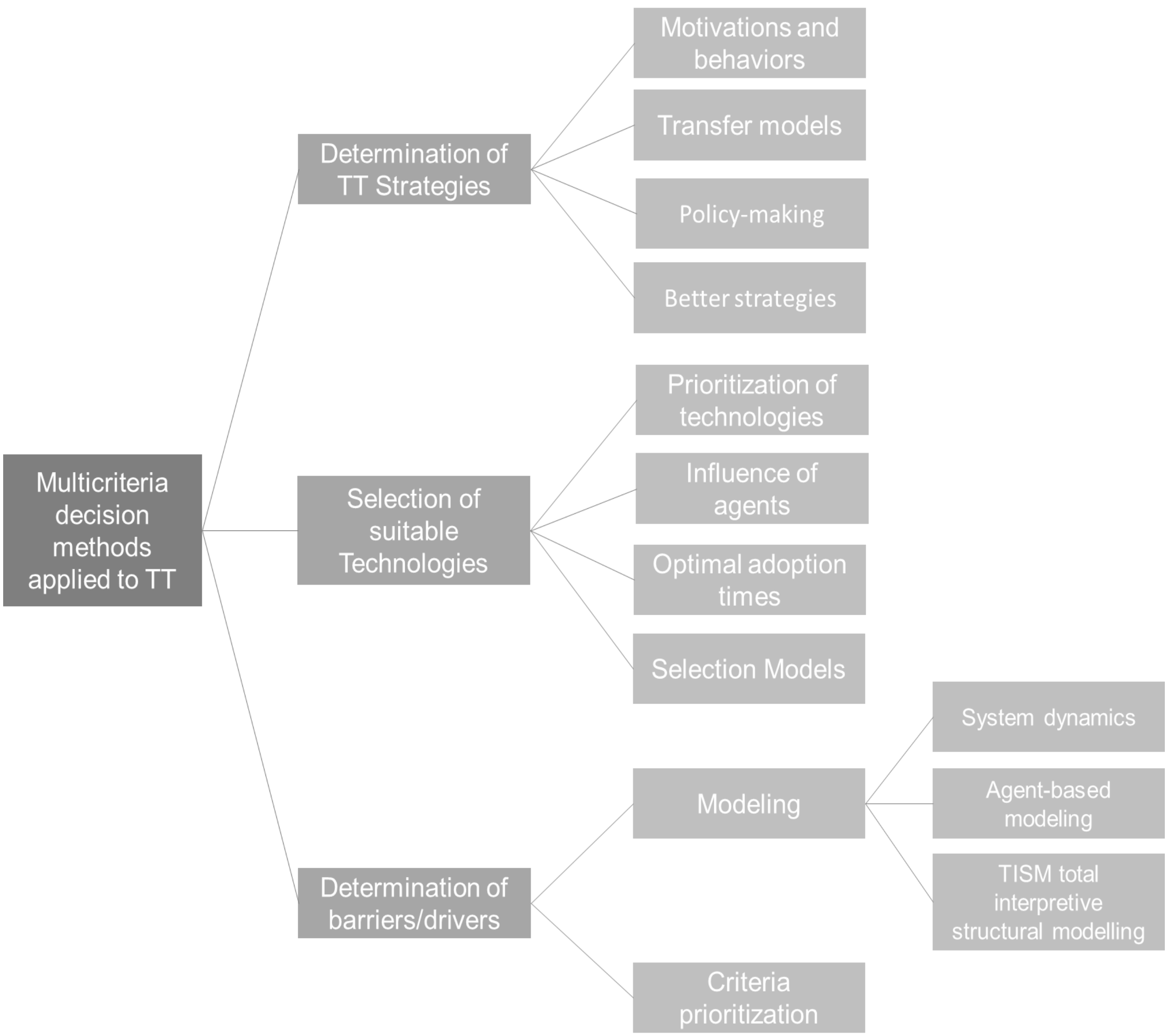


Figure 7. Tree of research trends around MCDM in technology transfer.

**Determination of TT strategies**

Table 4 presents the in-depth analysis of the scientific production around the research trend in "Determination of TT strategies".

Table 4. Results of the analysis of the research trend in Determination of TT strategies.

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| (Dinmohammadi and Shafiee, 2017) | (AHP) and the technique for order of preference by similarity to ideal solution (TOPSIS) | They determine the most suitable technology transfer strategy for wind turbines | Renewable Energies (Wind Turbines) | Iran |
| (Servati, 2017) | Fuzzy TOPSIS | A model for technology transfer policymaking based on Fuzzy Topsis is proposed, all of this combined with scenario planning methods. | Gas Industry | Iran |
| (Mutingi, 2014) | System dynamics | The effect of complex dynamics on adoption peak, peak adoption time, and in general, technology diffusion curves was evaluated to provide policy-building elements. | Information and communication technologies | No informati on available |
| (Mutingi and Matope, 2013)<br><br>(Mutingi, 2013a) | System dynamics | Performs a dynamics-based simulation of technology adoption processes to assess the relationship between technology adopters and policymakers | Renewable Energies | No informati on available |
| (Mutingi, 2013b) | Fuzzy logic and system dynamics | The aim is to improve policies related to the adoption and transfer of technologies by modeling typical global economic-energy scenarios | Renewable Energies | No informati on available |
| (Bosma *et al.*, 2010) | Fuzzy logic | A Model is developed using Fuzzy Logic that reveals farmers' motivation in integrating or adopting technologies | Farming | Vietnam |
| (Schreinemacher s and Berger, 2011) | Mathematical Programming-based Multi-Agent Systems (MP-MAS) | Describes the simulation of agricultural decision-making under dynamic markets, environmental change, and political intervention, which can affect human behavior and interactions. | Farming | Chile, Germany, Ghana, Thailand, Uganda, and Vietnam. |
| (Secundo *et al.*, 2016) | Fuzzy analytical hierarchy process | A technology transfer model for universities based on non-monetary criteria is developed | Academic | UK |
| (Yoon *et al.*, 2011) | Analytic hierarchy process and input-output analysis | A technology transfer model is developed for the marine sector, focused on the early stage (selection of technology and country of transfer) | Marine | South Korea and the Philippin es |
| (Chehrehpak, 2012; Huang, 2012) | Analytic hierarchy process | Development of a suitable transfer model for a gas sector company | Gas Industry | Iran |
| | Choquet Integral Based Multi-Criteria | Explores the mechanisms that should be assessed for the development of | Electronic | Taiwan |

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| | Assessment | an efficient technology transfer model | | |
| (Wen-Hsiang and Chien-Tzu, 2008) | Fuzzy set theory and analytic hierarchy process (AHP) | Develop a rule-based decision support mechanism to assess the effectiveness of the transfer process | Machinery industry | Taiwan |
| (Talaei *et al.*, 2014) | Analytic hierarchy process (AHP) | Multi-criteria decision techniques are applied to prioritize technologies in a country and to develop policies to facilitate technology transfer. | Renewable Energies | Iran |
| (Pinto *et al.*, 2019) | Decision-Making Trial and Evaluation Laboratory (DEMATEL) | Develop a multi-criteria model called KTT-GSCM Multi-criteria Model, and prioritize the factors that are relevant to Green Supply Chain Management (GSCM) along with Knowledge and Technology Transfer (KTT) and Innovation | Green supply chains (GSCs) | No information available |
| (Trivedi *et al.*, 2021) | Analytic hierarchy process (AHP), | Explores and prioritizes smartphone adoption factors using the technology acceptance model (TAM) and multi-attribute utility theory (MAUT) | Smart Phone | India |
| (Yadegaridehkordi *et al.*, 2019) | Grey Relational Analysis (GRA), Classification and Regression Trees (CART), and Fuzzy Rule-Based (FRB) | Develop a comprehensive decision-making model for predicting the level of adoption based on the significant adoption factors and their relationships | Software as a Service (SaaS) | Malaysia |
| (Çakır and Ulukan, 2020) | Fuzzy Multi-Objective Linear Programming (FMOLP) and Fuzzy Multiple Weighted-Objective Linear Programming (FMWOLP) | Propose a model for solving the nuclear power plant installation problem in fuzzy environment. | Energy (Nuclear energy) | No information available |

**Motivations and behaviors**

Bosma *et al.* (2010) show through a 10-stage Fuzzy Logic model that family motives and profit maximization are the most relevant factors when it comes to being successful in processes transfer for the agricultural sector. On the other hand, Schreier (2012) perform a Mathematical Programming-based Multi-Agent Systems (MP-MAS) exploration to evaluate how agricultural innovations and policies in developing countries affect heterogeneous populations of farmers, the results are compared against eight other simulators of interactions of the human environment.

**Transfer models**

The selection of an appropriate technology transfer (TT) method/model is a complex multidimensional problem, which involves a multitude of situational qualitative and quantitative criteria (Amirghodsi *et al.*, 2020). In a research conducted by Yoon *et al.* (2011), the development of a technology transfer model for the marine sector focused on the early stage (selection of technology and transfer country), based on AHP and analysis input-output is suggested. For the selection of the technology and the country to which to transfer, 5 criteria are identified (marketing, operational, environmental, economic, and political-social) and 15 sub criteria. Finally, to assess the impact of technology transferred in the country, an input-output analysis is made to determine value-added ability and employment generates. In another study by Huang (2012) the author proposes a model based on *Choquet Integral Based Fuzzy* that attempts to solve the complex aspects of technology transfer models by adding multiple fuzzy aspects to improve the aggregation of problem ratings. To evaluate the efficiency of technology transfer processes, Secundo *et al.* (2016) propose the construction of a model that uses non-monetary indicators according to different levels of technological maturity in developing countries. Non-monetary indicators are prioritized and weighted using the fuzzy analytical hierarchy process (AHP) since it employs a fuzzy set theory, based on 6 criteria; strategy and policy, organizational structure and design, human resources, technology, links with industry and networking, another 29 sub-criteria were identified and used to build the model. Other study developed by Lavoie and Daim (2020) create a multi-criteria decision-making (MCDM) model to evaluate an organization's technology transfer capabilities using action research and hierarchical decision modeling to bridge the gap between theory and practice and help practitioners in measuring and improving their technology transfer capabilities (Lavoie and Daim, 2020). Amirghodsi *et al.* (2020) developed a Multi-Criteria Group Decision-Making (MCGDM) method, as well as fuzzy and gray systems theories, to address uncertainties related to data collection and selection of TT methods and criteria for the building industry. This method reduces the uncertain associated to human judgment at the moment to select the appropriate strategy to incorporate technologies.

**Policymaking**

Regarding the design of technology transfer policies, the researches have been mainly approached from simulation models. Mutingi (2013b); Mutingi and Matope (2013) approach from the dynamics of systems to understand the behavior in the process of adoption of renewable energy technologies, understanding the complex dynamics of interaction between technology transferee, those responsible for technology construction and policies. The model starts with the identification of the factors that influence the complex dynamics of the adoption process, a loop causative analysis is developed, considering fuzzy variables for the formulation of policies considering variables and interrelation between key factors. In another study by Mutingi (2014) the behavior of a typical process of diffusion and adoption of technologies is addressed from the Systems Dynamics approach and the actors that are linked to the process, technology managers, and policymakers, with the aim of obtaining a deep understanding of the dynamics of adoption. Simulation results show that complex dynamics affect maximum adoption rate, peak adoption time, and general diffusion curve shape. A multi-criteria model for building and implementation of policies related to technology transfer was developed by (Talaei *et al.*, 2014), where AHP was applied to prioritize the technological needs of a country. The study enabled a set of policy recommendations to facilitate low-carbon technology transfer.

**Better strategies**

These focus on two main aspects: measuring process effectiveness itself or designing effective transfer strategies. Research related to this trend focuses on measuring the effectiveness of the technology transfer process using AHP and Fuzzy Sets, attempting to assess the influence of factors such as organization, talent, industry and technology through consultation with the experts (Wen-Hsiang and Chien-Tzu, 2008). Chehrehpak (2012) identifies the best technology transfer strategies, for this the AHP is applied through the evaluation of factors and subfactors to define the best strategy that an Iranian gas company should adopt. As a result, a ranking is delivered whose best method is the alliance, followed by training and education, exchange of personnel in third place, repurchase agreement, and finally payment of license in position 5.

Dinmohammadi and Shafiee (2017) developed a combined method between AHP and TOPSIS for the selection of the most appropriate transfer strategy for the design and manufacture of wind turbine systems, the proposed model consists of four criteria (economic, social, technical, and environmental) and nine determined sub-criteria from the point of view of wind farm investors, manufacturers, and operators. Research by Servati (2017) for the gas industry in Iran, implements FTOPSIS to classify different transfer strategies considering different future scenarios. This model is implemented with four measures of similarity and three ideal solutions. According to the findings for the case of the gas industry, the two most appropriate strategies are Joint Venture and payment of licenses.

Other research carried by (Komleh and Fazlollahtabar, 2019) applied a Stochastic Multi-Criteria Acceptability Analysis for Technology Transfer Evaluation in Construction Digging.

**Selection of suitable Technologies**

Table 5 presents the in-depth analysis of scientific production around the research trend in "Selection Technology."

Table 5. Results of the analysis of the research trend in Selection Technology.

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| (Huang *et al.*, 2013) | Bayesian Decision Analysis and Decision Trees | Identify the optimum time to adopt a technology | Foods | Taiwan |
| (Gąbka and Filcek, 2017) | Analytical Hierarchy Process (AHP) | Develops and implements a decision support system for the choice of technology and contractors. AHP is applied in the first phase, and a NP-complex problem is applied in the second phase. | Additive manufacturing in the automotive sector (turbochargers) | Poland |
| (Thampi and Rao, 2015) | Analytical Hierarchy Process (AHP) and Simple Additive Weighting (SAW) | Develop a tool for decision-making on municipal solid waste management technologies | Solid Waste | India |
| (Chen and Ma, 2017) | Stochastic optimization problem | Implements an optimization model for systematic technology adoption based on different agents that interact in decision-making | No information available | China |
| (Vera-Montenegro *et al.*, 2014) | AHP and Fuzzy logic | Implementation of a post-harvest technology selection model for cocoa growers, considering the fermentation and drying stages | Agriculture (Cocoa) | Ecuador |
| (Vera-Montenegroa *et al.*, 2014) | AHP and Fuzzy logic | Conduct a comparative analysis of the results achieved in the selection of technology with two multi-criteria tools | Agriculture (Cocoa) | Ecuador |
| (Lee and Chou, 2016) | Fuzzy Delphi, Fuzzy AHP and Fuzzy TOPSIS | The purpose of this study was to explore a technology selection process that involves a diffuse multi-criteria decision-making approach in three phases to facilitate the effective assessment of emerging technologies. | Electronics (semiconductors) | Taiwan |
| (Aliakbari Nouri *et al.*, 2015) | Fuzzy Analytic Network Process (FANP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) | A hybrid model for classifying technologies based on the Fuzzy Analytic Network Process (FANP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) is proposed. | Manufacture | Iran |
| (Vrana and Aly, 2010) | Hierarchical fuzzy systems | They propose a model to evaluate and select technologies, through the participation of industrial experts | Industrial | No informatio n available |
| (Onar *et al.*, 2015) | IVIF (interval-valued intuitionistic fuzzy) | Provides a model for decision-making in the selection of technologies based on linguistic assessments | Renewable Energies (Wind Turbines) | Turkey |

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| (Chansa and Srijuntub, 2010) | Analytic Hierarchy Process (AHP) | Select the most appropriate technology to be implemented by a government entity | Voice over Internet Protocol (VoIP) | Thailand |
| (Kim *et al.*, 2010) | Dual AHP (DAHP) | A multi-criteria decision method is applied to select emerging technologies for future R&D in a country | Electronics (Electric Vehicles) | South Korea |
| (Shen *et al.*, 2010) | Fuzzy Delphi method, analytic hierarchy process (AHP), and patent co-citation approach (PCA) | Develop a model for technology selection using the patent co-citation (PCA) method | Electronics (Organic Light-Emitting Diode or OLED) | Taiwan |
| (Yung-Hsiang, 2012) | Fuzzy analytic network process (FANP) | The FANP model is used to assess the strategic impact of new integrated circuit technologies | Electronics (semiconductors) | Taiwan |
| (Gossen *et al.*, 2016) | Promethee (Preference Ranking Organizational Method for Enrichment Evaluation) | A multi-attribute decision-making method is implemented to determine the most appropriate technology to avoid counterfeiting | Logistics (traceability) | Germany |
| (Jafarian and Vahdat, 2012) | Fuzzy analytical hierarchy process (AHP)-TOPSIS | A knowledge-based system was developed to identify the best materials welding process | Metal welding | Iran |
| (Yu *et al.*, 2011) | A combination of multi-attribute utility theory and exhaustive search optimization | A system for the selection of petroleum drilling technologies is developed based on exhaustive search optimization techniques | Oil (drilling operations) | USA |
| (Santos and Garcia, 2010) | Analytic Hierarchy Process (AHP), Multi-Attribute Failure Mode Analysis (MAFMA), Elimination and Choice Translating Reality (ELECTRE) | Propose a combined model for health technology evaluation, selection and incorporation | Medical technologies | No informatio n available |
| (Erbay and Yıldırım, 2018) | Analytical Hierarchy Process, Quality Function Deployment and Mixed Integer Programming methods | Different methods were used to prioritize, relate, and optimize the technological tools for their benefits to manufacturing operations on transportation industry | Transportation (Industry 4.0 technologies) | Turkey |
| (Heidary Dahooie *et al.*, 2021) | Fuzzy Delphi | Provides a framework for selecting the appropriate method of technology acquisition, considering uncertainty in hierarchical group decision-making | ICT (Interactive television technology) | Iran |
| (Dayo-Olupona *et al.*, 2020) | Analytic hierarchy process (AHP) and preference ranking organization method of enrichment (PROMETHEE) | Provide a multi-criteria method to select emerging technology in surface mines | Mining | No informatio n available |
| (Sadr *et al.*, 2020) | Analytic hierarchy process (AHP) | Development and application of a multi-objective-optimization and multi-criteria-based decision support | Water treatment technologies | India |

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| | | tool for selecting optimal technologies | | |
| (Beyaz and Yıldırım, 2019) | TOPSIS | Provides a decision-making model for identifying appropriate technologies for effective digital transformation in Automotive Supplier Industry | Transportation | Turkey |
| (Öztürk *et al.*, 2020) | Analytical hierarchy process (AHP)-TOPSIS | Presents a generic Multi-Criteria Decision Analysis (MCDA) model for Health Technology Assessment (HTA) decision-making, which can be applied to a wide range of HTA studies | Medical technologies | Turkey |
| (Chavosh Nejad *et al.*, 2021) | Analytical hierarchy process (AHP) | Proposes an integrated decision-making model to investigate the social sustainability of the technology management process (case study in banking industry) | Banking industry | Iran |

**Prioritization of technologies**

The application of multi-criteria decision methods for technology prioritization are diverse, one of those identified in the systematic literature review process was developed by Yu *et al.* (2011), This research shows the application of analytical decision methods for the selection of appropriate technology for the specific case of Green Lake in McFaddin, TX, all possible systems are evaluated to find an available system for oil drilling environmentally sustainable given the complexity of the larger problem variables may require greater computer processing capacity. Two investigations have been specially developed for the field of electronics, the first carried out by Yung-Hsiang (2012) applies the Fuzzy Analytic Network Process (FANP) process model to evaluate the strategic impact of new integrated circuit manufacturing technologies in companies within Taiwan's IC packaging industry. The study determined the most important decision-making factors that affect the selection of R&D projects using FANP, and an optimum manufacturing process was developed. Lee and Chou (2016) applied fuzzy methods for the prioritization and selection of emerging technologies in the semiconductor manufacturing area, a fuzzy Delphi was used to determine the importance of the criteria, then a FAHP to evaluate the weights of the criteria, and finally an FTOPSIS to order the solutions by preference and similarity. A study applied to the agricultural sector was conducted by Vera-Montenegro *et al.* (2014), in this study, a model for the selection of post-harvest cocoa technologies for small producers in Ecuador was developed, using AHP and fuzzy logic, to evaluate criteria of quality, cost of processing and capacity for technological adoption. It is concluded that fuzzy logic helps to understand decision-making since it presents linguistic stamps for the treatment of information. Another study related to environmental impact was developed by (Thampi and Rao, 2015), in which (AHP) and Simple Additive Weighting (SAW) were applied to select the most appropriate technology for the treatment and disposal of municipal solid waste in India, the results show that there is a relationship between institutional, sociocultural, political and environmental factors that affect the selection of the appropriate technology.

Gossen *et al.* (2016) implemented the PROMETHEE Preference Ranking Organizational Method for Enrichment Evaluation method, and a Multi-Attribute Decision-Making MADM method to select the most suitable technology to avoid the falsification of products. The method introduced follows a three-step approach: defining key dimensions of requirements, quantifying dimensions, and finally a multi-criteria priority model for countermeasures. Focusing on technology selection from an anti-counterfeiting point of view is the primary contribution of this study.

**Influence of agents**

Specifically, in this field Chen and Ma (2017) developed a stochastic optimization problem to assess the effect of agents (decision-makers) on the systematic adoption of technology, where each agent tries to identify optimal solutions by adopting technologies as part of a system. It is then explored how agents' heterogeneity and interactions affect systematic technology solutions.

**Optimal adoption times**

The adoption of new technology was modeled as a decision problem in which different uncertainty factors are considered to determine the optimal time of adoption of new technology. Huang *et al.* (2013), Bayesian decision analysis is conducted to include subjective judgments of decision-makers and market information.

**Selection Models**

Decision-makers' judgments are represented by exact numbers. However, in actual industrial applications, people prefer linguistic assessments rather than using precise numerical values due to inaccurate data, lack of information, and data vagueness. To resolve ambiguity and subjectivity in human judgments, different multi-criteria decision-making methods have been implemented and combined with a view to construct approximate models of reality and reduce risk in decisions (Onar *et al.*, 2015). The main investigations in this area were developed in 2010, Vrana and Aly (2010) developed an intelligent, practical, and adequate decision-making system for the evaluation of technologies, decision-making that deals with the associated vagueness and the quantification of many subjective measures, factors, and criteria involved in the context of technology transfer from industrial sectors, the above applying Fuzzy Logic and AHP.

For their part, Chansa and Srijuntub (2010) designed a model for selecting Voice over Internet Protocol (VoIP) technologies at governmental level, applied AHP and the criteria were grouped using the affinity diagram (K-J). The benefit, rather than low cost, is the main criteria. For sub-criteria, the intangible benefit is more important than the tangible benefit. On selection models specifically for countries, Kim *et al.* (2010) developed a selection model for emerging technologies for future R&D development applying Dual AHP, which consists of a regular AHP and Bayesian-type AHP. This DAHP performs useful functions when decomposing the main criteria is desirable, but not technically feasible through conventional methods. On the other hand, Shen *et al.* (2010) propose a technology selection process by applying the fuzzy Delphi method and AHP, they integrate into their proposal a patent co-citation approach (PCA), which makes it interesting given the contribution to the state of the technique in any area of knowledge of patents and utility models.

Finally, Aliakbari Nouri *et al.* (2015) propose a complex model to evaluate the appropriation of an organization's technologies and demonstrate model applicability in a real-life case study. FANP and FTOPSIS apply for its development.

**Determination of barriers/drivers**

As technology transfer is one of the most complex learning processes, an effective transfer may not be possible until all factors (known as "drivers" and obstacles called "barriers") are well explored and understood (Mutingi, 2014). In the same way, in developing countries these types of factors are faced, therefore, these critical barriers should be identified and eliminated for an effective technology transfer Kumar, Luthra, Haleem*, et al.* (2015). The following are the findings against these research trends.

**Modeling**

Robinson and Rai (2015) implemented an agent-based model to model the adoption of residential photovoltaic (PV) solar technology, the objective was to identify the characteristics of the model that are most important for the successful prediction of temporal, spatial, and demographic patterns that characterize the process of adopting photovoltaic solar energy technologies. The agent, topology, and environment variables are derived from detailed and comprehensive real-world data captured between 2004 and 2013 in Austin, Texas, USA. Technology adoption in food, energy, and water systems has been modeling using agent-based model to model, to represent and integrate human behavior, using multi-criteria decision methods to represent Agent decision-making and behavior ranged from reactive to active (Magliocca, 2020). Orjuela-Garzon *et al.* (2021) use the agent-based modeling paradigm (ABM) to analyze the Technology Adoption (AMTEC) Program on Rice Production in Colombia, using the geographical context, the interaction networks, and decision rules, to study the emergence at the macro-level of behavior patterns of a system from the interactions of semi-intelligent agents at the micro-level, using experiments.

**Criteria prioritization**

Various multi-criteria decision methods have been implemented to identify and prioritize critical factors that affect or facilitate technology transfer processes, including AHP, ANP, FANP, Delphi Method, Fuzzy Delphi, fuzzy set theory, TOPSIS, Table 6 presents the detail of the application of these methods. When conducting an in-depth review of the scientific documents, it is evident that for each geographic context, sector, or a specific application, factors and sub-factors are identified that influence both the process of technology transfer positively and negatively. Therefore, in each case of transfer, these critical factors must be evaluated to improve the effective transfer rate. Table 7 presents the key findings for this trend:

Table 6. Multi-criteria methods for assessing and prioritizing critical factors and subfactors.

| Method | Author | # Identified factors[1] | # Identified subfactors |
|---|---|---|---|
| AHP | (Lee *et al.*, 2012) | 7 | 23 |
| | (Kumar, Luthra and Haleem, 2015) | 6 | 20 |
| | (Kumar, Luthra, Haleem*, et al.*, 2015) | 5 | 24 |
| | (Wen-Hsiang and Chien-Tzu, 2008) | 4 | 15 |
| | (Mustafa Kamal and Alsudairi, 2009) | 5 | 21 |
| | (Gupta *et al.*, 2017) | 4 | 11 |
| | (Ma *et al.*, 2013) | 3 | 10 |
| ANP | (Lee *et al.*, 2009) | 5 | 21 |
| FANP | (Nilashi *et al.*, 2016) | 4 | 17 |
| | (Lee *et al.*, 2010) | 5 | 31 |
| Delphi | (Ma *et al.*, 2013) | 3 | 10 |
| Fuzzy Delphi | (Lee *et al.*, 2010) | 5 | 31 |
| Fuzzy set theory | (Wen-Hsiang and Chien-Tzu, 2008) | 4 | 15 |
| TOPSIS | (Tektas and Gozlu, 2008) | 5 | 14 |

Table 7. Research trend analysis in barrier and driver determination.

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| (Robinson and Rai, 2015) | Agent-based modeling | An agent-based modeling is performed to understand the interaction of agents from economic, social, and behavioral aspects. | (Renewable energy) (Residential use) | USA |
| (Khan et al., 2017) | TISM total interpretative structural model approach | Develops a TISM-based model not only to identify barriers to technology transfer but also their influence and dependency relationships | Green technologies | Developing countries |
| (Claire Erensal and Esra Albayrak, 2008) | Analytic hierarchy process (AHP) | Tries to identify factors affecting technology transfer success around micro and macro ergonomics | Manufacturing (kitchen and appliances) | Turkey |
| (Osabutey and Jin, 2016) | fuzzy set qualitative comparative analysis (fsQCA) t | Identifies factors affecting technology transfer through consulting experts and practitioners | Construction | Ghana |
| (Lee *et al.*, | Analytic hierarchy | Assesses the importance of | Electronics (E-paper, | South |

[1] The identified factors are detailed in table 4

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| 2012) | process (AHP) | Intangible priority factors and sub-factors for technology transfer | super capacity capacitor battery, RFID, bio-sensor, and Nano-CMOS) | Korea |
| (Kumar, Luthra and Haleem, 2015) | Analytic hierarchy process (AHP) | Critical barriers to technology transfer from a supply-chain approach are prioritized | No information available | No information available |
| (Kumar, Luthra, Haleem, *et al.*, 2015) | Analytic hierarchy process (AHP) | Identifies and assesses critical factors associated with technology transfer to suggest a strategic planning model | No information available | No information available |
| (Wen-Hsiang and Chien-Tzu, 2008) | fuzzy set theory and the method of Analytic Hierarchy Process (AHP) | The effectiveness of the transfer process is assessed through the study of critical factors | Machinery | Taiwan |
| (Lee *et al.*, 2010) | Fuzzy Delphi method (FM) and fuzzy analytic Newark process (FANP) | Identify critical transfer factors through a prioritization process and structural analysis | Electronics (the-film transistor liquid-crystal display (TFT-LCD) industry) | Taiwan |
| (Lee *et al.*, 2009) | Analytic network process (ANP) | Choosing the appropriate option among different modes of technology acquisition as alternatives by considering various factors as criteria | Software | South Korea |
| (Isgin *et al.*, 2008) | Zero-inflated Poisson and Negative Binomial count data model regressions | Technological adoption models based on probability of intensity of use are examined by identifying factors that affect farmers | Agriculture | USA |
| (Mustafa Kamal and Alsudairi, 2009) | Analytic hierarchy process (AHP) | Priority is given to relevant factors related to technology transfer for application integration for companies in the government sector. | Software (Business application integration) | UK |
| (Gupta *et al.*, 2017) | Analytic hierarchy process (AHP) | Factors related to the adoption of electronic government technologies are analyzed | Computing (electronic government) | India |
| (Nilashi *et al.*, 2016) | Fuzzy Analytic Network Process (ANP) | A model that provides ideas to understand the importance of influencing factors facilitating or inhibiting technological adoption decisions was developed | Computing (hospital information systems) | Malaysia |
| (Ma *et al.*, 2013) | Fuzzy analytic hierarchy process (FAHP) and Delphi method. | A model is developed to prioritize factors and their interdependence relationships, as well as technologies related to the potential for the sector of study | (Photovoltaic generation) | Taiwan |
| (Tektas and Gozlu, 2008) | TOPSIS | Technology transfer selection criteria are evaluated | Information and communication technology (GPRS) | Turkey |
| (Raj *et al.*, 2020) | (Grey-DEMATEL) | Ten barriers are identified for the adoption of autonomous vehicles | Transportation (autonomous | No information |

| Authors | Implemented method | Description | Application field | Country |
|---|---|---|---|---|
| | | | vehicles) | available |
| (Krmac and Djordjević, 2019) | Analytic hierarchy process (AHP) | Proposes a decision-making framework to support such a critical decision process through application of Strengths, Weaknesses, Opportunities, and Threats (SWOT) | Transportation (railway) | Europe |
| (Naicker and Thopil, 2019) | Analytic hierarchy process (AHP) | Proposes a framework that could be used to assess the various renewable energy technologies at utility scale. | Renewable energy (solar PV, wind, CSP, hydro, biogas, and biomass) | South Africa |
| (Mohammadi *et al.*, 2021) | Additive ratio assessment (ARAS) method and Fuzzy Delphi | Propose a hybrid approach for identifying and prioritizing critical success factors in technology transfer projects | Transportation (railway) | No information available |
| (Gupta and Goyal, 2021) | Fuzzy AHP-MICMAC (Cross-impact matrix multiplication applied to classification) - Interpretive structural modeling (ISM) | Identify and examine the reason and nature of barriers resisting the implementation of Big Data Analytics (BDA) | Manufacture sector (Big Data) | India |

**Main factors and subfactors identified**

The following is a summary of the most relevant factors and subfactors in the scientific documents referring to these trends (Table 8), eleven documents were considered in the in-depth review. A total of nine factors were identified (related to the transferor, related to the transferred, related to technology, related to the transfer environment, related to the appropriation of technology, related to sociocultural aspects, related to the politics, related to economic aspects, related to the market) and thirty-seven sub-factors.

Table 8. Principal factors and subfactors identified.

| Factor | Subfactor | Authors | Description |
|---|---|---|---|
| 1. Related to the transferor | 1. Transfer experience | (Lee *et al.*, 2012) (Tektas and Gozlu, 2008) | The know-how and tacit knowledge of those involved in the process from the transfer side facilitate the implementation and use of technology. |
| | 2. Brand power | (Lee *et al.*, 2012) | Refers to the position of the company that owns knowledge against the competition in the sector. |
| | 3. Successful transfer cases | (Lee *et al.*, 2012) | The success cases with which the total mastery of the knowledge or technology to be transferred can be demonstrated to the potential transferred and the market. |
| | 4. After-sale service | (Lee *et al.*, 2012; Kumar, Luthra, Haleem, *et al.*, 2015; Lee *et al.*, 2010) (Gupta *et al.*, 2017; Nilashi *et al.*, 2016; Ma *et al.*, 2013) | It refers to the technical and administrative capacity to support after the transfer phase and thus guarantees solution to any inconvenience that could happen. |
| 2. Related to the transferee | 5. Management attitude | (Kumar, Luthra and Haleem, 2015) | A positive attitude can play an important role and greatly influence the |

| Factor | Subfactor | Authors | Description |
|---|---|---|---|
| | | | organization's transfer of appropriate technology. |
| | 6. Management support | (Nilashi *et al.*, 2016; Mustafa Kamal and Alsudairi, 2009) | Management's commitment in turn commits the entire organization chart to the activities and importance of the process. |
| | 7. Employee attitude | (Kumar, Luthra and Haleem, 2015) | In some organization's employees are reluctant to purchase technology from external sources. |
| | 8. Employees' knowledge | (Mustafa Kamal and Alsudairi, 2009; Gupta *et al.*, 2017; Nilashi *et al.*, 2016) | Academic level, training, and experience facilitate the technology transfer process. |
| | 9. Company size | (Wen-Hsiang and Chien-Tzu, 2008; Lee *et al.*, 2009) | Organization size can influence transfer selection, robust organizations may have adequate resources for research, whereas small organizations may be forced to acquire under other channels. |
| | 10. Previous experience | (Wen-Hsiang and Chien-Tzu, 2008) | Previous successful experiences in technological cooperation with other firms can positively impact the new processes that are undertaken. |
| | 11. Seniority of the organization | (Wen-Hsiang and Chien-Tzu, 2008) | Young and middle-aged companies are more likely to register patents and utility models, while older companies are likely to acquire explicit knowledge through licenses. In addition, older companies are likely to secure capital alliances, while middle-aged companies establish collaborative technology partnerships. |
| | 12. Training | (Gupta *et al.*, 2017) | Training and pre-training, during and after transfer, may facilitate expected outcomes by the organization. |
| 3. Related to technology | 13. Complexity or sophistication | (Kumar, Luthra and Haleem, 2015; Wen-Hsiang and Chien-Tzu, 2008; Mustafa Kamal and Alsudairi, 2009; Nilashi *et al.*, 2016) | If the technology requires high knowledge, skill and experience for its operation or handling, problems may arise in its adoption and appropriation. |
| | 14. Coding | (Lee *et al.*, 2009; Tektas and Gozlu, 2008; Wen-Hsiang and Chien-Tzu, 2008) | Technology coding indicates the degree of difficulty in which a hardware is understood, as it involves aspects of replicability, imitability, and appropriability (Teece et al., 1997) |
| | 15. Level of technology innovation | (Ma *et al.*, 2013) | The level of technology innovation can be a favorable aspect around the Market and support that can be delivered to the products derived under its use or implementation, for customers it is synonymous with endorsement. |
| | 16. Stability and security of technology | (Lee *et al.*, 2010; Mustafa Kamal and Alsudairi, 2009; Nilashi *et al.*, 2016) | If the technology is fully assessed, breakdowns or corrections in the use process can be minimized. |
| 4. Related to the transfer | 17. Effective communication | (Kumar, Luthra and Haleem, 2015; Wen-Hsiang and Chien- | Interaction between the two parties plays a key role, so a clear, positive, and |

| Factor | Subfactor | Authors | Description |
|---|---|---|---|
| environment | | Tzu, 2008; Tektas and Gozlu, 2008) | understandable message can lead to satisfaction during transfer friction. |
| | 18. Lack of time | (Kumar, Luthra and Haleem, 2015) | The technology transfer process must have a time limit and time frame, so it must be clearly defined and recognized before implementation begins by the parties involved. |
| | 19. Culture | (Wen-Hsiang and Chien-Tzu, 2008) | When the parties share similar cultures, this can facilitate relationships and expected performance. |
| | 20. Attitude | (Wen-Hsiang and Chien-Tzu, 2008) | Parties' attitude to support transfer activities is a key factor. A positive attitude leads to a greater chance of success in the process. |
| | 21. Education | (Wen-Hsiang and Chien-Tzu, 2008) | The educational background of the transferor and transfer affects success or failure during TT processing; especially when transfer technology is complex. |
| 5. Related to the appropriation of technology | 22. Technology royalties | (Lee *et al.*, 2012) | Depending on firm size, maturity, and intellectual property portfolio, the parties can negotiate more efficiently. |
| | 23. Duration of licensing | (Lee *et al.*, 2012) | When licensing is limited, parties should quickly prepare strategies for negotiating or changing providers. |
| | 24. Terms of contracting | (Lee *et al.*, 2010) | Clear business by the parties guarantees the success of adoption and transfer, any aspect outside the contract may have negative effects in the negotiation process. |
| 6. Related to sociocultural aspects | 25. Cultural judgment | (Kumar, Luthra and Haleem, 2015) | Partners from diverse cultures may face relevant interaction difficulties at the outset and during processes. |
| 7. Related to politics | 26. Cooperation between actors | (Kumar, Luthra and Haleem, 2015) | Efficient accompaniment and cooperation processes guarantee the degree of success of the process, any break in cooperation leaves the success of the process at stake. |
| | 27. Policy instability | (Kumar, Luthra and Haleem, 2015; Wen-Hsiang and Chien-Tzu, 2008) | Changing policies in research, technological development, and innovation can stimulate or delay negotiation processes between the parties. |
| 8. Related to economic aspects | 28. Acquisition costs | (Kumar, Luthra and Haleem, 2015; Lee *et al.*, 2009; Mustafa Kamal and Alsudairi, 2009) | The firm's economic capacity determines the level of technology innovation. |
| | 29. Repair and maintenance costs | (Lee *et al.*, 2010) | These costs may be included in acquisition negotiations since if they're not assumed by the transferor, it could affect ROI. |
| | 30. Uncertainty in the return on investment | (Kumar, Luthra and Haleem, 2015; Mustafa Kamal and Alsudairi, 2009; Nilashi *et al.*, 2016; Kumar, Luthra, Haleem, | If the transferor is not clear about the competitive advantage that the technology to transfer gives him/her over his/her competitors, it is difficult to |

| Factor | Subfactor | Authors | Description |
|---|---|---|---|
| | | *et al.*, 2015) | assess the ability to recover the investment. |
| | 31. Profit margins | (Kumar, Luthra, Haleem, *et al.*, 2015) | If profit margins are not attractive, one should look for other transfer methods that reduce costs and increase ROI feasibility. |
| | 32. Financial resources | (Nilashi *et al.*, 2016; Tektas and Gozlu, 2008) | The financial capability supports negotiation with the owner of the technology |
| 9. Related to the market | 33. Market size | (Wen-Hsiang and Chien-Tzu, 2008) | The size of the market may indicate to the transferee the scale or capacity of technology required. |
| | 34. New areas of penetration | (Kumar, Luthra, Haleem, *et al.*, 2015) | If the acquired technology provides a competitive advantage, it could impact the generation of new market niches to penetrate (quality, price, and novelty). |
| | 35. Increased use by current customers | (Kumar, Luthra, Haleem, *et al.*, 2015) | If acquired technology gives the product greater added the value, it can affect value proposition and generate greater customer use and massification. |
| | 36. Product life cycle | (Wen-Hsiang and Chien-Tzu, 2008; Lee *et al.*, 2009) | Indicates the evaluation that the firm must conduct on the technology to acquire new terms, i.e., maturity. |
| | 37. Increase in sales | (Kumar, Luthra and Haleem, 2015) | The potential increase in sales by the transferor must be assessed before the acquisition of the technology, and thereby be clear about the potential that the hardware has in growing the organization. |

## CONCLUSION AND RECOMMENDATIONS

A systematic literature review associated with the application of multi-criteria decision-making methods applied to transfer technologies was carried out, a total of 153 scientific documents were identified, of which a total of 67 related to this field of study were reviewed in depth, three main research perspectives were established: (i) Determination of technology transfer strategies, (ii) selection of suitable technologies and (iii) determination of barriers and drivers, besides, of 10 subareas of interest. Information was gathered regarding the 9 factors and 37 subfactors that facilitate or restrict the transfer process. This relevant contribution of the review could facilitate the definition and evaluation of Technology Acceptance Models in different sectors, which contemplate not only the barriers and facilitators of the end-user but also a systemic view that involves the transferor and diffuser using techniques such as system dynamics or agent-based modeling. This simulation techniques allow for a better understanding of the dynamics and behavior patterns that emerge in the technology transfer process in a bottom-up and top-down perspective. Findings show the significance of application of the Hierarchical analysis method (AHP) and the fuzzy logic applications, there is also a growing interest in identifying and selecting emerging technologies for the sectors of computing, transportation, agriculture, electronics, and software. For decision makers and policymakers, these methods can facilitate the generation of strategies as they eliminate ambiguity, imprecision, subjectivity in human judgment, and uncertainty when conducting multi-criteria ratings by experts for TT processes, in addition, using linguistic variables that facilitate some methods exposed in the review improves the handling of complex decision system.

## REFERENCES

Aliakbari Nouri, F., S. Khalili Esbouei and J. Antucheviciene. 2015. A Hybrid MCDM

Approach Based on Fuzzy ANP and Fuzzy TOPSIS for Technology Selection. Informatica, 26: 369-88.

Amirghodsi, S., A. Bonyadi Naeini and B. Roozbehani. 2020. An Integrated Shannon-PAF Method on Gray Numbers to Rank Technology Transfer Strategies. Engineering Management Journal, 32: 186-207.

Audretsch, D. B., E. E. Lehmann and M. Wright. 2012. Technology transfer in a global economy. The Journal of Technology Transfer, 39: 301-12.

Beyaz, H. F. and N. Yıldırım. 2019. A Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing: A Case Study from Automotive Supplier Industry. Springer International Publishing. Place Published. pp.217-32.

Bosma, R., U. Kaymak, J. van den Berg, H. Udo and J. Verreth. 2010. Using fuzzy logic modelling to simulate farmers' decision-making on diversification and integration in the Mekong Delta, Vietnam. Soft Computing, 15: 295-310.

Çakır, E. and Z. Ulukan. 2020. Fuzzy multi-objective decision making approach for nuclear power plant installation. Journal of Intelligent & Fuzzy Systems, 39: 6339-50.

Chansa, C. N. and A. Srijuntub. 2010. Using Analytic Hierarchy Process for innovative technology selection: a case study. International Journal of Innovation and Learning, 8: 279.

Chavosh Nejad, M., S. Mansour and A. Karamipour. 2021. An AHP-based multi-criteria model for assessment of the social sustainability of technology management process: A case study in banking industry. Technology in Society, 65: 101602.

Chehrehpak, M. 2012. Selecting of optimal methods for the technology transfer by using analytic hierarchy process (AHP). Indian Journal of Science and Technology, 5: 1-7.

Chen, H. and T. Ma. 2017. Optimizing systematic technology adoption with heterogeneous agents. European Journal of Operational Research, 257: 287-96.

Claire Erensal, Y. and Y. Esra Albayrak. 2008. Transferring appropriate manufacturing technologies for developing countries. Journal of Manufacturing Technology Management, 19: 158-71.

Dayo-Olupona, O., B. Genc and M. Onifade. 2020. Technology adoption in mining: A multi-criteria method to select emerging technology in surface mines. Resources Policy, 69: 101879.

Díaz-Díaz, N. L., I. Aguiar-Díaz and P. De Saá-Pérez. 2008. The effect of technological knowledge assets on performance: The innovative choice in Spanish firms. Research Policy, 37: 1515-29.

Dinmohammadi, A. and M. Shafiee. 2017. Determination of the Most Suitable Technology Transfer Strategy for Wind Turbines Using an Integrated AHP-TOPSIS Decision Model. Energies, 10: 642.

Erbay, H. and N. Yıldırım. 2018. Technology Selection for Digital Transformation: A Mixed Decision Making Model of AHP and QFD. Springer International Publishing. Place Published. pp.480-93.

Forrester, J. W. 2007. System dynamics—a personal view of the first fifty years. System Dynamics Review, 23: 345-58.

Gąbka, J. and G. Filcek. 2017. Multiple Criteria Decision Support System for Making the Best Manufacturing Technologies Choice and Assigning Contractors. Springer International Publishing. Place Published. pp.314-23.

Gossen, E., E. Abele and M. Rauscher. 2016. Multi-criterial Selection of Track and Trace Technologies for an Anti-counterfeiting Strategy. Procedia CIRP, 57: 73-78.

Gupta, A. K. and H. Goyal. 2021. Framework for implementing big data analytics in Indian manufacturing: ISM-MICMAC and Fuzzy-AHP approach. Information Technology and Management, 22: 207-29.

Gupta, K. P., P. Bhaskar and S. Singh. 2017. Prioritization of factors influencing employee adoption of e-government using the analytic hierarchy process. Journal of Systems and Information Technology, 19: 116-37.

Gwo-Hshiung, T. and H. Jih-Jeng. 2011. Multiple Attribute Decision Making: Methods and Applications. Taylor & Francis. Place Published.

Heidary Dahooie, J., A. R. Qorbani and T. Daim. 2021. Providing a framework for selecting the appropriate method of technology acquisition considering uncertainty in hierarchical group decision-making: Case Study: Interactive television technology. Technological Forecasting and Social Change, 168: 120760.

Huang, C.-Y. 2012. The non-additive Choquet integration in the Fuzzy DNP framework for evaluating Co-dependent technology transfer models. IEEE. Place Published.

Huang, Y.-S., T.-L. Hsueh and G.-H. Zheng. 2013. Decisions on optimal adoption time for new technology. Computers & Industrial Engineering, 65: 388-94.

Hwang, C.-L. and K. Yoon. 1981. Methods for Multiple Attribute Decision Making. Springer Berlin Heidelberg. Place Published. pp.58-191.

Isgin, T., A. Bilgic, D. L. Forster and M. T. Batte. 2008. Using count data models to determine the factors affecting farmers' quantity decisions of precision farming technology adoption. Computers and Electronics in Agriculture, 62: 231-42.

Ishikawa, A., M. Amagasa, T. Shiga, G. Tomizawa, R. Tatsuta and H. Mieno. 1993. The max-min Delphi method and fuzzy Delphi method via fuzzy integration. Fuzzy Sets and Systems, 55: 241-53.

Jafarian, M. and S. E. Vahdat. 2012. A fuzzy multi-attribute approach to select the welding process at high pressure vessel manufacturing. Journal of Manufacturing Processes, 14: 250-56.

Khabiri, N., S. Rast and A. A. Senin. 2012. Identifying Main Influential Elements in Technology Transfer Process: A Conceptual Model. Procedia - Social and Behavioral Sciences, 40: 417-23.

Kim, W., S. K. Han, K. J. Oh, T. Y. Kim, H. Ahn and C. Song. 2010. The dual analytic hierarchy process to prioritize emerging technologies. Technological Forecasting and Social Change, 77: 566-77.

Komleh, A. A. and H. Fazlollahtabar. 2019. Stochastic Multi-Criteria Acceptability Analysis for Technology Transfer Evaluation: A Case Study in Construction Digging. International Journal of Mathematical, Engineering and Management Sciences, 4: 1031-39.

Krmac, E. and B. Djordjević. 2019. A Multi-Criteria Decision-Making Framework for the Evaluation of Train Control Information Systems, the Case of ERTMS. International Journal of Information Technology & Decision Making, 18: 209-39.

Kumar, S., S. Luthra and A. Haleem. 2015. Benchmarking supply chains by analyzing technology transfer critical barriers using AHP approach. Benchmarking: An International Journal, 22: 538-58.

Kumar, S., S. Luthra, A. Haleem, S. K. Mangla and D. Garg. 2015. Identification and evaluation of critical factors to technology transfer using AHP approach. International Strategic Management Review, 3: 24-42.

Lavoie, J. R. and T. Daim. 2020. Towards the assessment of technology transfer capabilities: An action research-enhanced HDM model. Technology in Society, 60: 101217.

Lee, A. H. I., W.-M. Wang and T.-Y. Lin. 2010. An evaluation framework for technology transfer of new equipment in high technology industry. Technological Forecasting and Social Change, 77: 135-50.

Lee, H., S. Lee and Y. Park. 2009. Selection of technology acquisition mode using the analytic network process. Mathematical and Computer Modelling, 49: 1274-82.

Lee, S., W. Kim, Y. M. Kim and K. J. Oh. 2012. Using AHP to determine intangible priority factors for technology transfer adoption. Expert Systems with Applications, 39: 6388-95.

Lee, Y.-C. and C. Chou. 2016. Technology Evaluation and Selection of 3DIC Integration Using a Three-Stage Fuzzy MCDM. Sustainability, 8: 114.

Ma, D., C.-C. Chang and S.-W. Hung. 2013. The selection of technology for late-starters: A case study of the energy-smart photovoltaic industry. Economic Modelling, 35: 10-20.

Magliocca, N. R. 2020. Agent-Based Modeling for Integrating Human Behavior into the Food–Energy–Water Nexus. Land, 9: 519.

Mohammadi, N., J. Heidary Dahooie and M. Khajevand. 2021. A hybrid approach for identifying and prioritizing critical success factors in technology transfer projects (case study: diesel locomotive manufacturing). Journal of Engineering, Design and Technology, ahead-of-print.

Mustafa Kamal, M. and M. Alsudairi. 2009. Investigating the importance of factors influencing integration technologies adoption in local government authorities. Transforming

Government: People, Process and Policy, 3: 302-31.

Mutingi, M. 2013a. Adoption of Renewable Energy Technologies: A Fuzzy System Dynamics Perspective. Springer New York. Place Published. pp.175-96.

———. 2013b. Understanding the dynamics of the adoption of renewable energy technologies: A system dynamics approach. Decision Science Letters, 2: 109-18.

———. 2014. System dynamics of information technology adoption in a complex environment. International Journal of Industrial and Systems Engineering, 17: 78.

Mutingi, M. and S. Matope. 2013. System dynamics of renewable energy technology adoption. IEEE. Place Published.

Naicker, P. and G. A. Thopil. 2019. A framework for sustainable utility scale renewable energy selection in South Africa. Journal of Cleaner Production, 224: 637-50.

Nilashi, M., H. Ahmadi, A. Ahani, R. Ravangard and O. b. Ibrahim. 2016. Determining the importance of Hospital Information System adoption factors using Fuzzy Analytic Network Process (ANP). Technological Forecasting and Social Change, 111: 244-64.

Onar, S. C., B. Oztaysi, İ. Otay and C. Kahraman. 2015. Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets. Energy, 90: 274-85.

Orjuela-Garzon, W., S. Quintero, D. P. Giraldo, L. Lotero and C. Nieto-Londoño. 2021. A Theoretical Framework for Analysing Technology Transfer Processes Using Agent-Based Modelling: A Case Study on Massive Technology Adoption (AMTEC) Program on Rice Production. Sustainability, 13: 11143.

Orjuela, W. A., W. A. Araque Echeverry and R. A. Cabrera Pedraza. 2020. Identificación de tecnologías y métodos para la detección temprana del Huanglongbing (HLB) a través de cienciometría en artículos científicos y patentes. Ciencia & Tecnología Agropecuaria, 21.

Osabutey, E. L. C. and Z. Jin. 2016. Factors influencing technology and knowledge transfer: Configurational recipes for Sub-Saharan Africa. Journal of Business Research, 69: 5390-95.

Öztürk, N., H. Tozan and Ö. Vayvay. 2020. A New Decision Model Approach for Health Technology Assessment and A Case Study for Dialysis Alternatives in Turkey. International journal of environmental research and public health, 17: 3608.

Pinto, M. M. A., J. L. Kovaleski, R. T. Yoshino and R. N. Pagani. 2019. Knowledge and Technology Transfer Influencing the Process of Innovation in Green Supply Chain Management: A Multicriteria Model Based on the DEMATEL Method. Sustainability, 11: 3485.

Raj, A., J. A. Kumar and P. Bansal. 2020. A multicriteria decision making approach to study barriers to the adoption of autonomous vehicles. Transportation Research Part A: Policy and Practice, 133: 122-37.

Robinson, S. A. and V. Rai. 2015. Determinants of spatio-temporal patterns of energy technology adoption: An agent-based modeling approach. Applied Energy, 151: 273-84.

Saaty, T. L. 1990. The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation. McGraw-Hill. Place Published.

Sadr, S. M. K., M. B. Johns, F. A. Memon, A. P. Duncan, J. Gordon, R. Gibson, H. J. F. Chang, M. S. Morley, D. Savic and D. Butler. 2020. Development and Application of a Multi-Objective-Optimization and Multi-Criteria-Based Decision Support Tool for Selecting Optimal Water Treatment Technologies in India. Water, 12: 2836.

Santos, F. A. and R. Garcia. 2010. Decision process model to the health technology incorporation. IEEE. Place Published.

Schreier, M. 2012. Qualitative content analysis in practice. Sage publications.

Schreinemachers, P. and T. Berger. 2011. An agent-based simulation model of human–environment interactions in agricultural systems. Environmental Modelling & Software, 26: 845-59.

Secundo, G., C. De Beer and G. Passiante. 2016. Measuring university technology transfer efficiency: a maturity level approach. Measuring Business Excellence, 20: 42-54.

Servati, Y. 2017. Robust technology transfer policy making using scenario based fuzzy topsis – a case study of iran's gas industry. Applied

Ecology and Environmental Research, 15: 593-610.

Shen, Y.-C., S.-H. Chang, G. T. R. Lin and H.-C. Yu. 2010. A hybrid selection model for emerging technology. Technological Forecasting and Social Change, 77: 151-66.

Talaei, A., M. S. Ahadi and S. Maghsoudy. 2014. Climate friendly technology transfer in the energy sector: A case study of Iran. Energy Policy, 64: 349-63.

Tektas, B. and S. Gozlu. 2008. General packet radio service (GPRS) technology transfer: A case study to evaluate transferors. IEEE. Place Published.

Thampi, A. and B. Rao. 2015. Application of Multi-criteria Decision Making Tools for Technology Choice in Treatment and Disposal of Municipal Solid Waste for Local Self Government Bodies—A Case Study of Kerala, India. The Journal of Solid Waste Technology and Management, 41: 84-95.

Trivedi, V., A. Chauhan and A. Trivedi. 2021. Analysing consumers' smartphone adoption decisions using qualitative dimensions: a multi-criteria decision approach. International Journal of Technology Marketing, 15: 48.

Vera-Montenegro, L., A. Baviera-Puig and J.-M. Garcia-Alvarez-Coque. 2014. AHP choice in cocoa post-harvest technology for small-scale farmers. Spanish Journal of Agricultural Research, 12: 542.

Vera-Montenegroa, L., A. Baviera-Puig and J.-M. Garcia-Alvarez-Coque. 2014. Selection of cocoa post-harvest technology using fuzzy logic. FUZZY ECONOMIC REVIEW, 19.

Vrana, I. and S. Aly. 2010. Assessing candidate industrial technologies utilising hierarchical fuzzy decision making systems. International Journal of Industrial and Systems Engineering, 6: 187.

Wen-Hsiang, L. and T. Chien-Tzu. 2008. Analyzing influence factors of technology transfer using fuzzy set theory. IEEE. Place Published.

Winebrake, J. J. 1992. A study of technology-transfer mechanisms for federally funded R&D. The Journal of Technology Transfer, 17: 54-61.

Yadegaridehkordi, E., M. Nilashi, L. Shuib, S. Asadi and O. Ibrahim. 2019. Development of a SaaS Adoption Decision-Making Model Using a New Hybrid MCDM Approach. International Journal of Information Technology & Decision Making, 18: 1845-74.

Yoon, B., C. Lee and J. Hwang. 2011. A framework for impact analysis of the international transfer of marine technology in a climate change era: an input-output analysis and analytic hierarchy process approach. Asian Journal of Technology Innovation, 19: 1-19.

Yu, O. Y., S. D. Guikema, J. L. Briaud and D. Burnett. 2011. Quantitative decision tools for system selection in environmentally friendly drilling. Civil Engineering and Environmental Systems, 28: 185-208.

Yung-Hsiang, H. 2012. Applying the fuzzy analytic network process to the selection of an advanced integrated circuit (IC) packaging process development project. International Journal of the Physical Sciences, 7.

Zadeh, L. A. 1965. Fuzzy sets. Information and Control, 8: 338-53.